SUMMER SKIES Grab your binoculars and tour the Milky Way P52

PORTABLE SCOPE The ultimate Dobsonian telescope design P64

DOUBLE STARS Take part in a global observing program P60

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HOT PRODUCTS: OUR PICKS FOR 2016 P36

NZ's BEST ASTROPHOTOS P14

Einstein's universe

Hunting black holes, gravitational waves and new physics P22

TEST REPORT: Three beginner scopes P66

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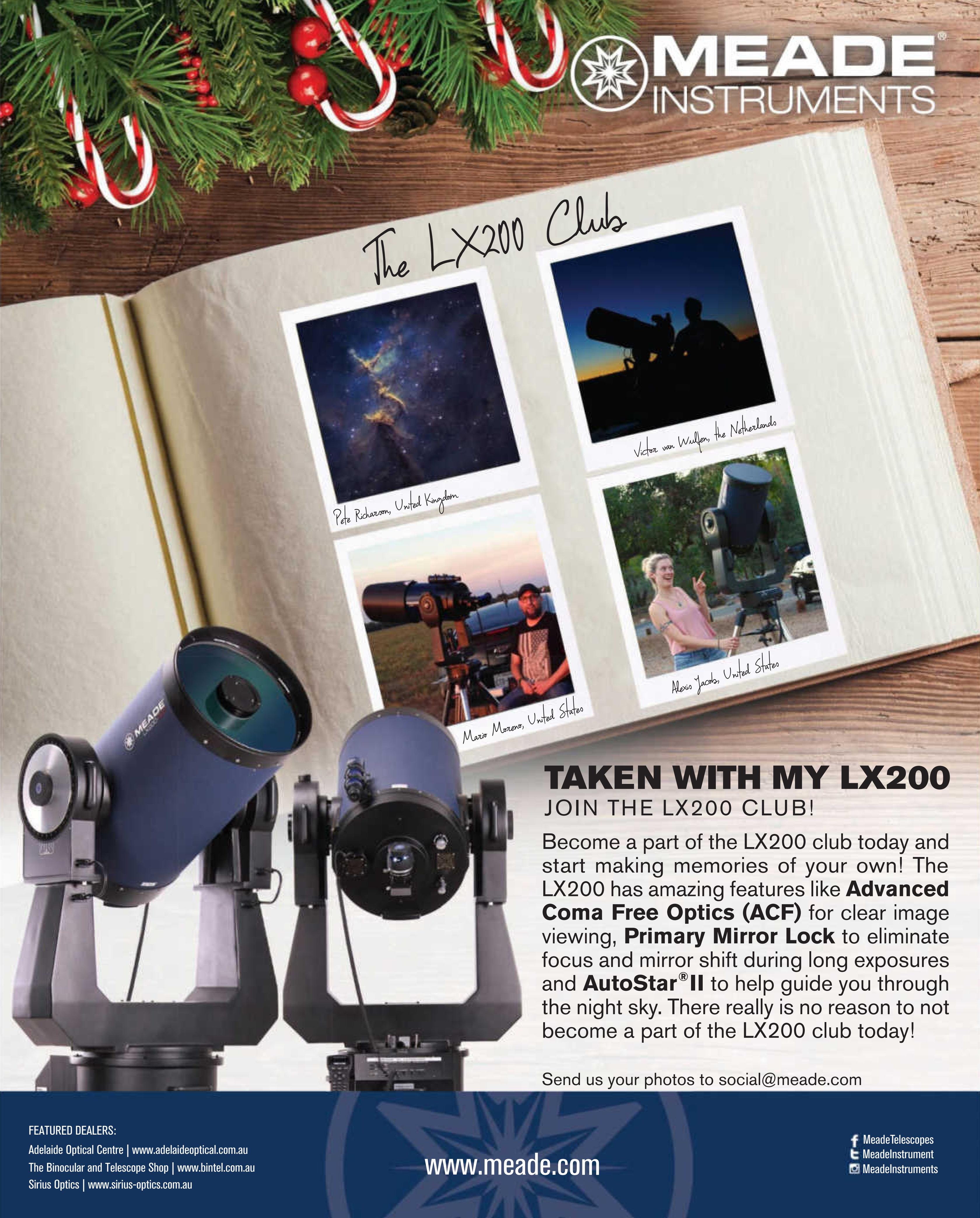
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January 2016 Vol. 12, No. 1

Contents

AUSTRALIAN SKY & TELESCOPE

REGULARS

5 **Spectrum**
By Jonathan Nally

8 **News notes**

12 **Discoveries**
By David Ellyard

74 **Astro Calendar**

p.14 New Zealand's pristine skies

FEATURES

14 **Aotearoa skies**
Winners of New Zealand's Harry Williams Astrophotography competition

22 **The age of General Relativity**
Albert Einstein published his general theory of relativity just over 100 years ago. Astronomy took 50 years to catch up. Now it's running the show.
By Pedro G. Ferreira

30 **Hunting ripples in spacetime**
A century after Einstein predicted their gravitational ways, scientists say they're on the verge of opening a revolutionary new window on the universe.
By Govert Schilling

36 **Hot products for 2016**
We've scoured the marketplace for what we consider to be some of the year's most exciting new products.

OBSERVING & EXPLORING

42 **Binocular highlight**
The splendid Pleiades
By Gary Seronik

44 **Tonight's sky**
Many ways to begin the new year
By Fred Schaaf

46 **Sun, Moon and planets**
The dance of Venus and Saturn
By Jonathan Nally

47 **Meteors**
Will the Alpha Centaurids put on a show?
By Con Stoitsis

48 **Comets**
Comet Catalina heads north
By David Seargent

49 **Double star notes**
Another visit to Taurus
By Ross Gould

50 **Variable stars**
A century of observations
By Alan Plummer

p.56 Explore a lunar basin

52 **Binocular Tour**
Take a trip along the Milky Way
By Mathew Wedel

56 **Exploring the Moon**
Lunar basin packed with features
By Charles A. Wood

60 **The double star project**
Your assistance is needed with a global observing program
By Sissy Haas

THE ASTRONOMY SCENE

64 Telescope workshop
A very versatile Dobsonian
By Gary Seronik

66 Test report
Three beginner's telescopes tested
By Tony Flanders

72 Book review
A new deep sky handbook is born
By Alan MacRobert

76 Gallery
Reader's astrophotos

79 Marketplace

80 Index to advertisers

82 Focal point
Getting the Soviets' stamp of approval
By Alex Gurshtein

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ON THE COVER:

New observatories in space and on the ground will put Einstein's theories to their final tests. See page 22.

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Einstein's breakthrough

It's now a little over 100 years since the world woke to the news of one of the most amazing intellectual accomplishments our species has ever known, with the publication of Albert Einstein's general theory of relativity (GR). And although his incredible leap in cosmic comprehension wasn't fully appreciated at the time — or for some years after in fact — GR has come to represent the most elegant and deceptively simple model of reality ever conceived.

Not only has GR changed our view of the cosmos, it has also changed our understanding of the very concepts of space and time. And what also is so remarkable about it is that has passed every test thrown at it, and has been used to make successful predictions for real phenomena that can be observed or inferred.

Such as black holes. Although we have lots of evidence that black holes exist, we've never seen one. That's somewhat understandable, as they don't give off any light of their own. All we've been able to see so far is the effect they have on their surroundings. But new telescopes (see page 22) promise soon to help us zoom in on the black holes themselves, until we're able to see the boundary between the holes and the swirling masses of material being drawn in toward them.

Gravitational waves are another natural outcome of Einstein's theory. Formed when masses accelerate, they are incredibly weak. So far, no detectors have been sensitive enough to spot them, but that soon will change. New instruments (page 30) are coming online that will be able to sense these space-time ripples spreading out from places where the most massive of objects are undergoing dramatic accelerations of one kind or another — such as the collapse of stars into black holes or collisions between neutron stars.

Once, all we had to work with was visible light. Then, slowly, the rest of the electromagnetic spectrum was opened up to us. Now, with gravitational waves, a new frontier in astrophysics is about to be unveiled. What will it reveal? Time will tell, but no doubt it will be amazing.

Jonathan Nally
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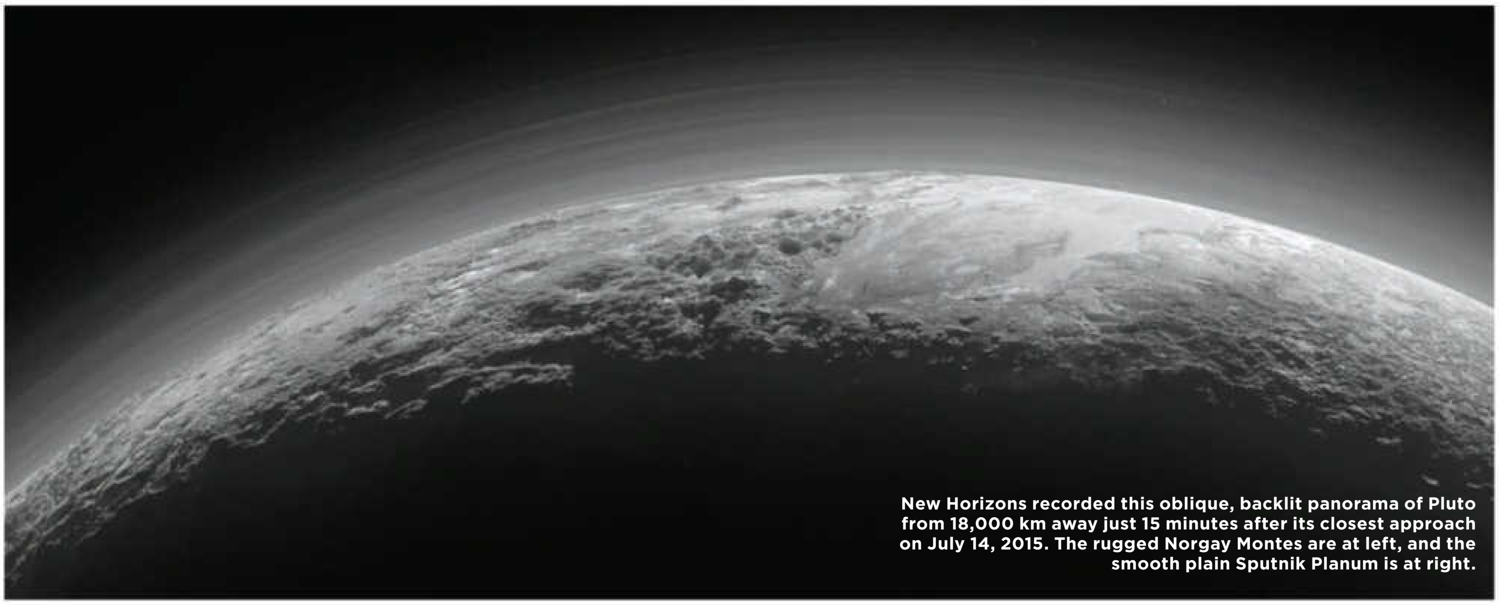


New Horizons recorded this oblique, backlit panorama of Pluto from 18,000 km away just 15 minutes after its closest approach on July 14, 2015. The rugged Norgay Montes are at left, and the smooth plain Sputnik Planum is at right.

NASA / JHU APL / SWRI (2)

Close-up of a binary dwarf planet

It's going to take a year for NASA's New Horizons spacecraft to send back all the images and other data it collected as it swept past Pluto on July 14, 2015, and the mission team has repeatedly promised that watching those observations trickle in will be like getting birthday presents every week. Two of those 'gifts' are shown here.

The spectacular backlit panorama of Pluto provides an oblique perspective that accentuates this little world's surprisingly rugged and varied terrain. "This image really makes you feel you are there, at Pluto, surveying the landscape for yourself," comments principal investigator Alan Stern (Southwest Research Institute).

Yet, more than a pretty picture, the high-phase-angle lighting provides important insights into all that's going on down below. For example, even though Pluto's atmosphere is incredibly tenuous, it's stacked with more than a dozen thin haze layers that extend from the icy ground up to altitudes of 100 km or more. The angular peaks informally dubbed Norgay Montes, which dominate the left side of the panorama, rise to elevations of about 3½ km (11,000 feet) — far higher than anyone expected. "The randomly jumbled mountains might be huge blocks of hard water ice floating within a vast, denser, softer deposit of frozen nitrogen," suggests lead geologist Jeff Moore (NASA Ames). "Think Silly Putty."

Meanwhile, planetary geologists don't yet know how or when Pluto's largest moon came to exist. But this much is certain: Charon has had a rough time of it in the eons since. Exhibit A is an enormous system of fractures girding the moon's midsection for at least 1,600 km — four times the Grand Canyon's length and twice as deep in spots — and it likely continues onto Charon's farside. This crevasse chain has the look of a huge tear, like crustal rending seen on Earth (the East African Rift, for example) and Mars (Valles Marineris).

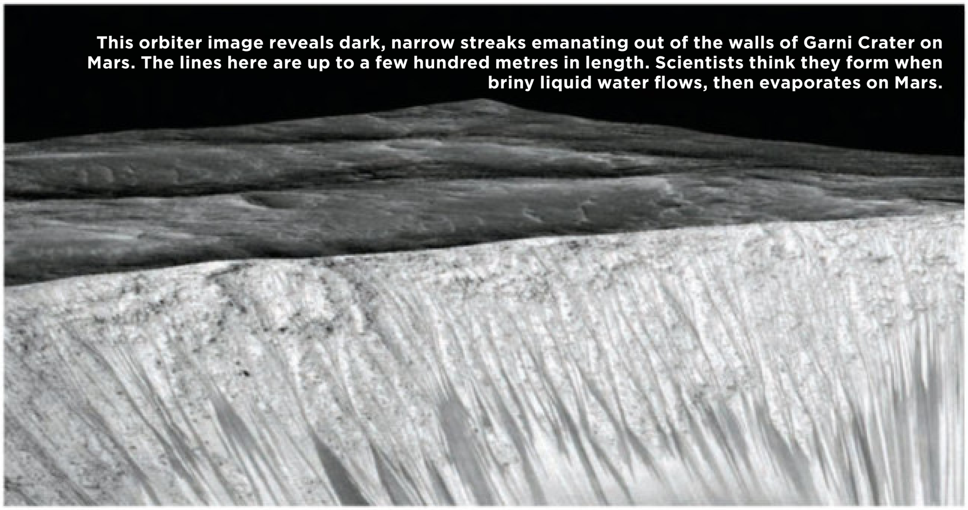
Canyons gird Charon's midsection, breaking up the moon's cratered terrain. To their south, the fractures give way to the smoother plain informally named Vulcan Planum. This scene, a combination of blue, red and infrared images, resolves details as small as 0.8 km.

"It looks like the entire crust of Charon has been split open," observes John Spencer (Southwest Research Institute), who serves as deputy lead for the mission's geology, geophysics and imaging team. Such wholesale extension might have occurred, the New Horizons team speculates, if Charon once had an interior ocean of water that expanded as it froze long ago. The overlying crust would have cracked wide open to accommodate the increased volume. Whatever the cause, the faults and canyons indicate some kind of global geologic upheaval in Charon's past.

The enigmatic, red-stained depression at Charon's north pole also defies explanation. One early speculation held that the reddish material is a veneer of organic compounds, synthesised from methane that escaped from Pluto. But the new images suggest that most of the reddish terrain is partly bounded by a high-standing rim. That wouldn't happen if the red material came from transplutonian space. Instead, some or all of it might have come from Charon's interior.

■ J. KELLY BEATTY

Waterlogged salts on Mars



This orbiter image reveals dark, narrow streaks emanating out of the walls of Garni Crater on Mars. The lines here are up to a few hundred metres in length. Scientists think they form when briny liquid water flows, then evaporates on Mars.

NASA / JPL / UNIVERSITY OF ARIZONA

Scientists have confirmed that water-soaked salts create dark, seasonal streaks on Mars. These *recurring slope lineae* (RSL) appear on sloping ground — such as crater walls — during warmer months on the Red Planet. Growing up to hundreds of metres long, they then fade as the temperature cools, only to reappear when temperatures rise again.

Reaching midday highs of at least –23°C, these areas are too cold for pure liquid water to create downhill flows. Instead, planetary scientists suggest salty water is to blame: salts lower water's freezing point enough that water could melt, creating briny flows just beneath the soil's surface.

But scientists have looked for years without spotting definitive signs of liquid water or hydrated salts in areas containing RSL. Lujendra Ojha (Georgia Institute of Technology) and colleagues have now found the latter, using observations by NASA's Mars Reconnaissance Orbiter. Instead of averaging spectra over large areas containing RSL, as done before, the researchers homed in on specific pixels dominated by the streaks. They looked at four RSL sites: the craters Palikir, Horowitz and Hale, and the valley Coprates Chasma.

The team found spectral matches in all four locations to salts that incorporate water in their molecular structure. (The team didn't detect liquid water itself, but the spacecraft observed during local mid-afternoon, when conditions are likely to be driest.) The researchers report in *Nature Geoscience* that, based on the spectral lines seen, the salts appear to be perchlorates and chlorates.

NASA's Phoenix lander detected perchlorates in 2008 at its far-northern landing site, and other lander and rover data support their presence elsewhere. These salts are particularly good at dissolving in water. The water probably picks them up from the subsurface soil and then, as it reaches the surface and evaporates, redeposits the salts but in higher concentrations. As the brines build up, they change the surface's colour and create the low-reflectivity streaks.

It's still unclear where the Martian water comes from. It might be from subsurface ice, though that shouldn't be buried at such shallow depths near the equator (which is generally where these streaks appear). Salty grains on the surface might instead grab so much water from the atmosphere that they dissolve and form a hyper-concentrated solution. Rovers have found Martian air is more humid than expected, but scientists don't know for sure whether the planet's atmosphere has enough water vapour for this grab-and-dissolve process, called *deliquescence*, to happen.

Wherever it's coming from, liquid water does seem to be flowing just below the surface of Mars.

■ CAMILLE M. CARLISLE

IN BRIEF

New mid-size black hole. Astronomers think a bright X-ray source in the galaxy NGC 1313 is an intermediate-mass black hole (IMBH). These elusive objects should range from a few hundred to a hundred thousand solar masses. Most IMBH candidates are iffy contenders. In 2014, Dheeraj Pasham (NASA Goddard) and colleagues weighed a potential IMBH using *quasi-periodic oscillations* (QPOs), cyclic blips in a black hole's X-ray signal that astronomers suspect are related to the object's mass. The team calculated a mass of roughly 400 Suns for the object, which lies in the galaxy M82. Now, the team estimates that a QPO-producing object in the galaxy NGC 1313 has a mass between 3,700 and 6,300 Suns. This would easily put it in the IMBH family and add to growing evidence that black holes do indeed exist on all scales. The result appears in *Astrophysical Journal Letters*. Read more about how the QPO method works at http://is.gd/qpoimbh.

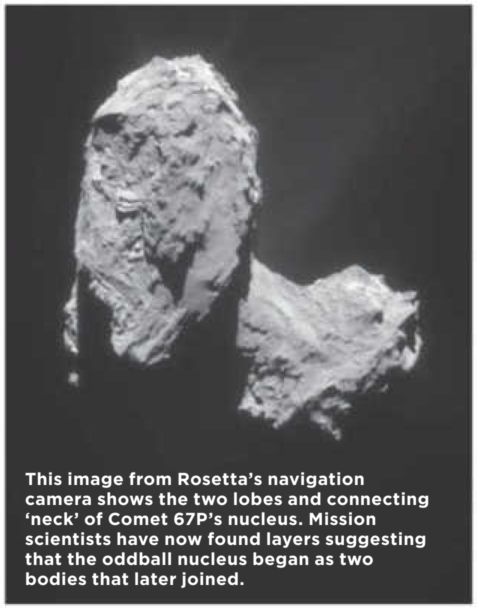
■ CAMILLE M. CARLISLE

Brightest galaxies powered by stars, not mergers. Astronomers long thought that major mergers were responsible for *submillimetre galaxies*, rare and brilliant stellar metropolises in the early universe that radiate powerfully as they create 500 to 1,000 Suns' worth of stellar mass every year. But new simulations reported in *Nature* by Desika Narayanan (Haverford College) and colleagues suggest otherwise. Tracking simulated galaxies' growth over about 2 billion years, the team found that the starburst (and submillimetre radiation-emitting) phase isn't a short, merger-inspired flash but a prolonged, luminous chapter that lasts roughly 750 million years — too long to be supported by mergers. Instead, stellar feedback maintains the star-forming reservoir: aging and exploding stars drive gas outward, which then cools and rains back down in a galactic-scale cycle.

■ MONICA YOUNG

Churyumov-Gerasimenko began as two comets

Rosetta observations confirm that the 'rubber ducky'-shaped nucleus of Comet 67P/Churyumov-Gerasimenko was likely born when two individual objects in the outer Solar System gently collided and stuck together.



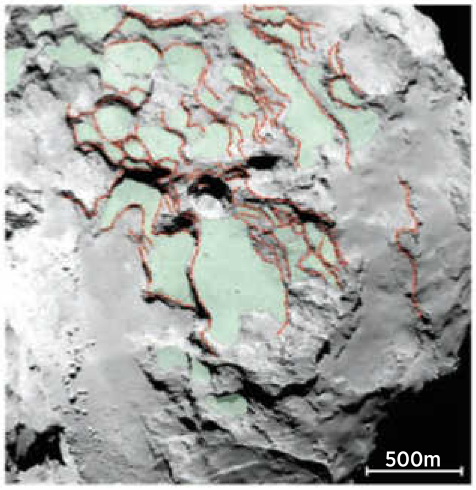
This image from Rosetta's navigation camera shows the two lobes and connecting 'neck' of Comet 67P's nucleus. Mission scientists have now found layers suggesting that the oddball nucleus began as two bodies that later joined.

ESA / ROSETTA / NAVCAM

Matteo Massironi (University of Padova, Italy) and colleagues used images from Rosetta's Optical, Spectroscopic, and Infrared Remote Imaging System (OSIRIS) to investigate the nucleus's origin. The scientists peered down into pits and along terraces and cliffs across the nucleus. They found strata like those seen in sedimentary rock on Earth, built up as the bodies formed one layer at a time. In some places the layers reach 650 metres deep, a fair fraction of the kilometres-long nucleus. You can think of them like the layers in an onion, the team explains in the journal *Nature*.

If Comet 67P's layering arose during the nucleus's formation (the most probable explanation), then the onion shells should form concentric rings around their parent body's centre of mass. If the nucleus began as one object, then the strata in the duck's head and body would encircle a single centre; if it began as two, then the body and head strata would have centres in their respective lobes.

The team found that the layers do encircle two different centres, one in each lobe. Thus, Comet 67P's nucleus began as two separate bodies. Layering observed in other comet nuclei during spacecraft flybys supports the idea that these objects likewise formed by accreting layers over time.



ESA / ROSETTA / MPS FOR OSIRIS TEAM MPS / UPD / LAM / IAA / SSO / INTA / UPM / DASP / IDA; M. MASSIRONI ET AL. 2015

This image from the Rosetta spacecraft shows terraces in the Seth region, near the nucleus's neck. Green marks main terraces and red dashed lines mark exposed layers.

■ **CAMILLE M. CARLISLE**

New evidence for binary quasar

Astronomers have confirmed that the quasar PG 1302-102 is probably a binary supermassive black hole, its components less than a tenth of a light-year apart.

Recently, Matthew Graham (Caltech) and colleagues found several dozen quasars glowing with regular beats, one of which was PG 1302-102. This discovery surprised them, because black holes are usually fickle emitters. The best explanation for the periodic behaviour was that the quasars are actually two black holes spiraling toward each other. The years between signals would then be the orbital period.

But scientists didn't know *why* the periodicity exists. Daniel D'Orazio (Columbia University) and colleagues now think they have the answer. They realised that, if a smaller black hole were circling a larger one, we would see a *Doppler boost* in the quasar's emission.

Doppler *shifts* are the change in light's wavelength because its source is moving toward (blueshifted) or away (redshifted) from us. Doppler boosting is this effect on steroids. With PG 1302-102's black holes so close together, the smaller one is whipping around its bigger sibling at 7% the speed of light. That dramatically shifts the wavelength by 14%. So if we're observing the quasar at an optical wavelength of 600 nm, that means that when the smaller black hole is moving toward us, we're actually seeing 700-nm light that's been blueshifted, but when it's moving away, we're seeing 530-nm light that's been redshifted.

If the quasar's emission were the same intensity at all wavelengths, then we wouldn't notice a difference. But its intensity increases from optical to ultraviolet. So a 14% change in wavelength samples different intensities, meaning that as the small black hole orbits, we see a periodic change — the mysterious beat.

If this scenario is correct, the team reports in the journal *Nature*, then PG 1302-102's variations ought to be more than twice as large at ultraviolet wavelengths as at optical ones. That's because the quasar's emission doesn't just get brighter from optical to ultraviolet — it also brightens more rapidly with wavelength. So if the optical emission shifts toward a shorter wavelength, we'll see a bit of an increase in intensity, but if the ultraviolet emission shifts the same amount, we'll see a greater increase in intensity.

The team compared PG 1302-102's multiwavelength variations using archival spectra from the Hubble (optical) and Galaxy Evolution Explorer (ultraviolet) space telescopes. The astronomers found the expected extra oomph in ultraviolet.

■ **CAMILLE M. CARLISLE**

RESONANT WAVES MIGHT HEAT SUN'S CORONA

Astronomers have detected waves working together in the solar atmosphere, creating turbulence that superheats the corona's ionised gas.

The Sun's corona is more than a hundred times hotter than the photosphere below it. One explanation for this temperature surge is *Alfvénic waves*, motions in the solar plasma governed by the magnetic field. The corona is essentially a sea of these waves. Solar physicists think that the waves carry enough energy to heat the corona — but pinning down how the magnetic motions do it has been tough.

New spacecraft observations, coupled with computer simulations, might solve the mystery. Takenori Okamoto (JAXA), Patrick Antolin (National Astronomical Observatory of Japan), and their team watched threads of superheated plasma wiggle in 3D in a coronal filament. These prominences are cooler and denser than the surrounding corona, making them easier to observe.

Using these data, the researchers realised it's how the waves add together that matters. Seen from the side, the threads vibrate with *transverse waves*, as a plucked guitar string does. But the threads also twist toward and away from us, just as your hand twists one way, then the other, on your wrist. When these two types of vibrations travel at the same speed, they resonate with the same beat.

Guided by simulations, the team suggests in two papers in the *Astrophysical Journal* that the waves' resonance causes the guitar-string waves to transfer their energy to the twist waves, pumping up their motion. This in turn exacerbates the shear between the threads' boundaries and the thinner, hotter gas in the atmosphere around them, creating eddies. The eddies combine to create larger-scale turbulence. And the turbulence, due to the friction and electrical currents it creates, steals the wave energy from the threads and dumps it into the coronal plasma, heating it.

■ **CAMILLE M. CARLISLE**

White dwarfs with hiccups

Observations of two cool white dwarfs show irregular outbursts in the stars' otherwise steady rhythm of pulsations. Pulsating white dwarfs, or ZZ Ceti stars, are a type of white dwarf that glows and fades in a steady rhythm. White dwarfs start to pulse when they cool from an initial temperature of around 100,000K to about 12,600K. The atmosphere becomes a mix of ionised and neutral hydrogen atoms, and this mix stores and releases energy in regular intervals of a few minutes, driving pulsations. These make the white dwarf brighten and fade by a few percent in regular beats, like a person's rhythmic breathing. The star continues to cool slowly over time, but once it falls below about 10,800K, it ceases pulsating altogether.

Using Kepler data, which has far fewer gaps than ground-based observations, J. J. Hermes (University of Warwick, UK) and colleagues tracked two pulsating white dwarfs, KIC 4552982 and PG 1149+057. The temperatures of the two stars are both about 11,000K, cooler than most ZZ Cetis previously studied. The team discovered that hiccups interrupted the dwarfs' otherwise even pulsations. Shooting high above the expected crests and falls in brightness every few minutes appeared sporadic outbursts lasting several hours. The regular pulsations change the stars' brightness by 1% to 3%, but KIC 4552982's outbursts were 2% to 17% above the norm, and PG 1149+057's hiccups spiked up to 45% above the star's mean brightness. As the researchers report in the *Astrophysical Journal* and *Astrophysical Journal Letters*, they don't know why these outbursts happen, but the surges might be the dwarfs' last gasps before pulsations shut down.

■ **NATALIA GUERRERO**

India's first astronomy satellite

Indian astrophysics got a boost on September 28 when the Indian Space Research Organisation (ISRO) launched the Astrosat spacecraft into a low-altitude orbit. The multipurpose observatory will study the universe across the X-ray spectrum, accompanied by simultaneous visible- and ultraviolet-light observations.

India has successfully sent spacecraft to the Moon and Mars and, more recently, has lofted X-ray detectors aboard high-altitude balloons and suborbital sounding rockets. But this is ISRO's first astronomical satellite. It's capable of studying everything from nearby white dwarfs, pulsars and supernova remnants to faraway galaxy clusters. Its data will be available to the Indian astronomy community via proposals for observations.

Astrosat's five instruments each observe a different wavelength range. They comprise low-resolution X-ray spectral instruments, a binocular Ritchey-Chrétien telescope, and a detector with a huge 10°-by-90° field of view that will scan the sky for transient X-ray sources.

The project is essentially a combination of NASA's Swift and now-retired Rossi X-ray Timing Explorer (RXTE) satellites. Like Swift, Astrosat will hunt for X-ray transients and observe these sources across the visible-to-X-ray spectrum. And like RXTE, Astrosat will measure the arrival time of each photon. Its Large Area Xenon Proportional Counters (LAXPC) have the largest collecting area of any X-ray instrument ever built, and it's currently the only one capable of studying X-ray fluctuations over millisecond time scales.

Astrosat joins several other X-ray observatories already in orbit: Chandra makes out fine details in low-energy X-ray images, NuSTAR brings high-energy X-rays into sharp focus, Swift monitors the sky for distant explosions bright in X-rays and gamma rays, and ESA's XMM-Newton is a light bucket for low-energy X-rays. ✦

■ **DAVID DICKINSON**

Huygens' journey to Titan

Humankind's first mission to the surface of an outer-Solar System body

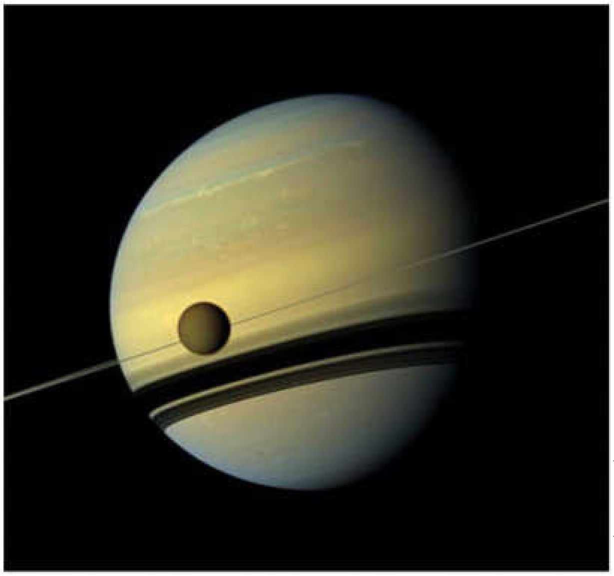
Touching down on another world remains a rare and exciting event. It hadn't happened at all, of course, until the dawn of the Space Age nearly sixty years ago, and for most of the years since such encounters were limited to nearby bodies of the Solar System. We have made soft landings (ie. the package of instruments survived in working order) on the Moon many times, on Mars quite a few times, and even on Venus and a comet. But only once was the target situated in the outer Solar System, in the vast realm beyond the asteroid belt where the giant planets rule.

That meeting was with Saturn's largest moon, and it took place on January 14, 2005, barely a decade ago. The spacecraft was called Huygens, named after a leading astronomer and clock-maker of the 17th century, the brilliant Dutchman Christiaan Huygens. His achievements included the first sighting of the orange dot near Saturn which English astronomer John Herschel later called Titan, after the figures in Greek mythology who were the siblings of the god Chronos (Saturn to the Romans).

Titan remained an enigma for long after its discovery, although we eventually learned that Titan was the only known satellite with an appreciable atmosphere (as thick as ours in fact), mostly nitrogen but with a substantial trace of methane. Chemical reactions fill the atmosphere with smog, providing the notable orange colour but hiding the surface from view. This gave rise to speculation that the landscape might hold lakes of liquid methane. The only way to settle that and many other questions, would be to go there (as had been done in the similar case of cloud-obscured Venus).

Huygens arrived at the Saturn system as part of a larger mission, built around the Cassini spacecraft (acknowledging another major name from the 17th century, the Italian-French Domenico Cassini who, inter alia, discovered the true nature of Saturn's rings, a task that defeated the great Galileo). The brilliantly successful Cassini mission is still traversing the Saturn system to this day, making multiple close passes of the planet's moons and returning stunning pictures. Cassini released Huygens on Christmas Day 2004; six weeks later a heatshield and parachute helped the probe descend through Titan's atmosphere to touch down on the surface.

Huygens' handlers had no idea if the landing would work or if the spacecraft survive. What if it dropped into one of the suspected lakes or onto the side of a mountain and tumbled to destruction? A few minutes of data from the six instruments aboard would have been judged a success; only three hours of battery power had been provided.



Saturn's largest moon, Titan, floats in front of the giant planet in this Cassini spacecraft image.

NASA/JPL-CALTECH/SSI

As it turned out, the mission had enjoyed some luck. The probed worked for 90 minutes, radioing home (via Cassini) a stream of data and images. It appeared that Huygens had landed near the shoreline of one of the lakes, the existence of which had been confirmed with imaging during the descent. Underneath the spacecraft was what looked to be a drainage channel into the lake, strewn with boulders, most likely of water ice stained by a rain of organic chemicals.

Huygens carried a 10-Watt transmitter with an ultra-stable frequency. Watchers back on Earth were able to detect its transmissions directly (as well as via Cassini) and to use Doppler shifts in the frequency of the returning signal to measure just how the craft was blown about as it descended. Much as expected, winds above 150 km altitude hit 400 km per hour, though the landing took place in a dead calm.

Huygens is now long dead, perhaps slowly corroding on that distant shore, but it did its job well. Titan remains a source of interest, in part because of the similarity between its atmosphere and that of the early Earth. Some have speculated on the possibility of some life-form surviving there, despite the cold (Huygens recorded –190°C), with a biochemistry based on methane. Any confirmation of that must await another mission.✦

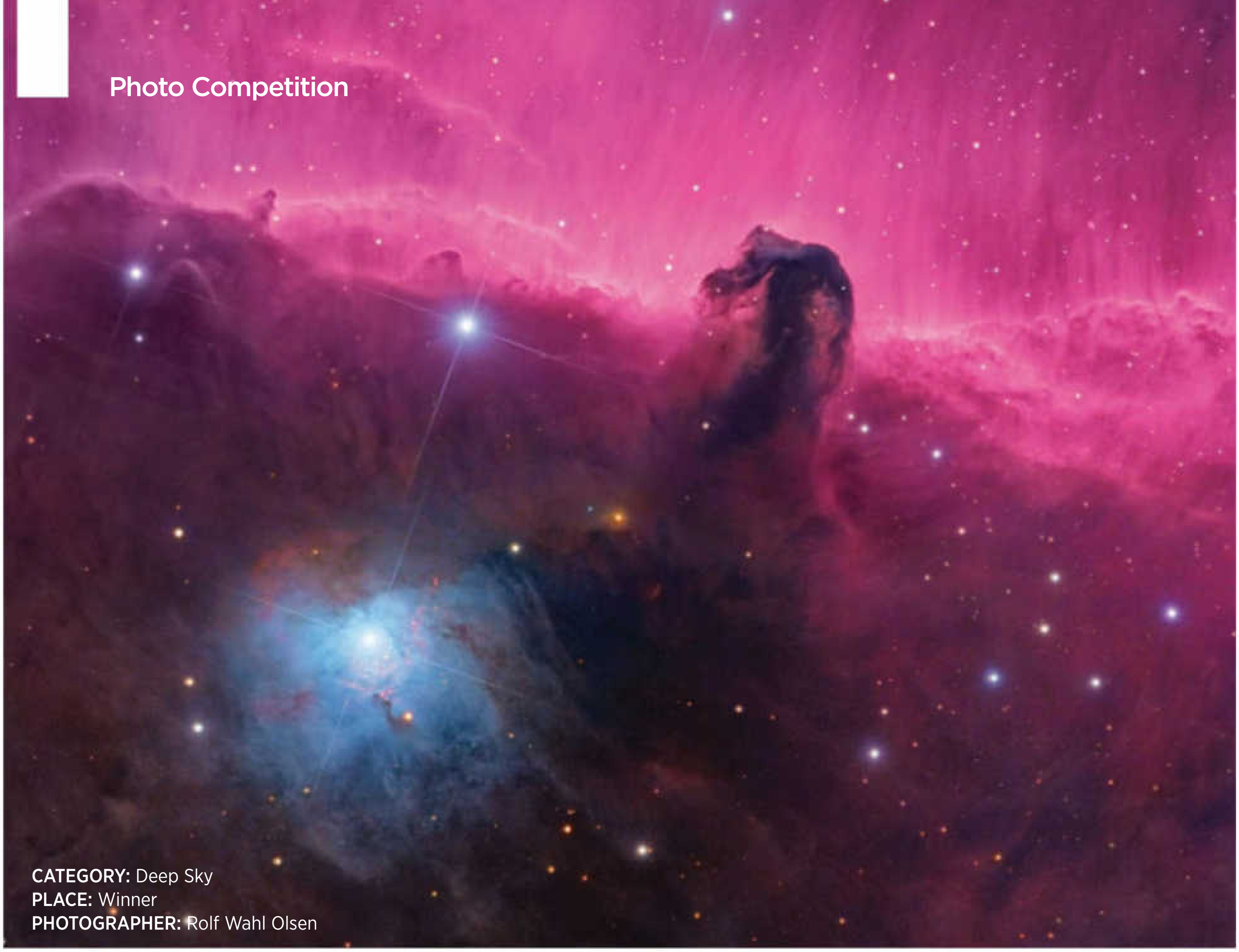
__David Ellyard__ presented SkyWatch on ABC TV in the 1980s. His StarWatch StarWheel has sold over 100,000 copies.

Aotearoa Skies

THE 2015 HARRY WILLIAMS ASTROPHOTOGRAPHY COMPETITION

The Auckland Astronomical Society's annual Harry Williams Astrophotography Competition is New Zealand's largest and most popular astro-imaging contest — and 2015 saw some incredible sky shots submitted, giving expert judge Pete Lawrence a difficult job to pick the very best. On these pages, we present the winning and highly commended images in each of the categories. *Australian Sky & Telescope* is proud to have been the sponsor for the Solar System and Artistic categories. Aotearoa Astrophotography sponsored the Newcomers category; the Deep Sky category was sponsored by the Nikon D810a.

OVERALL WINNER AND WINNER IN THE ARTISTIC CATEGORY
PHOTOGRAPHER: Lee Cook

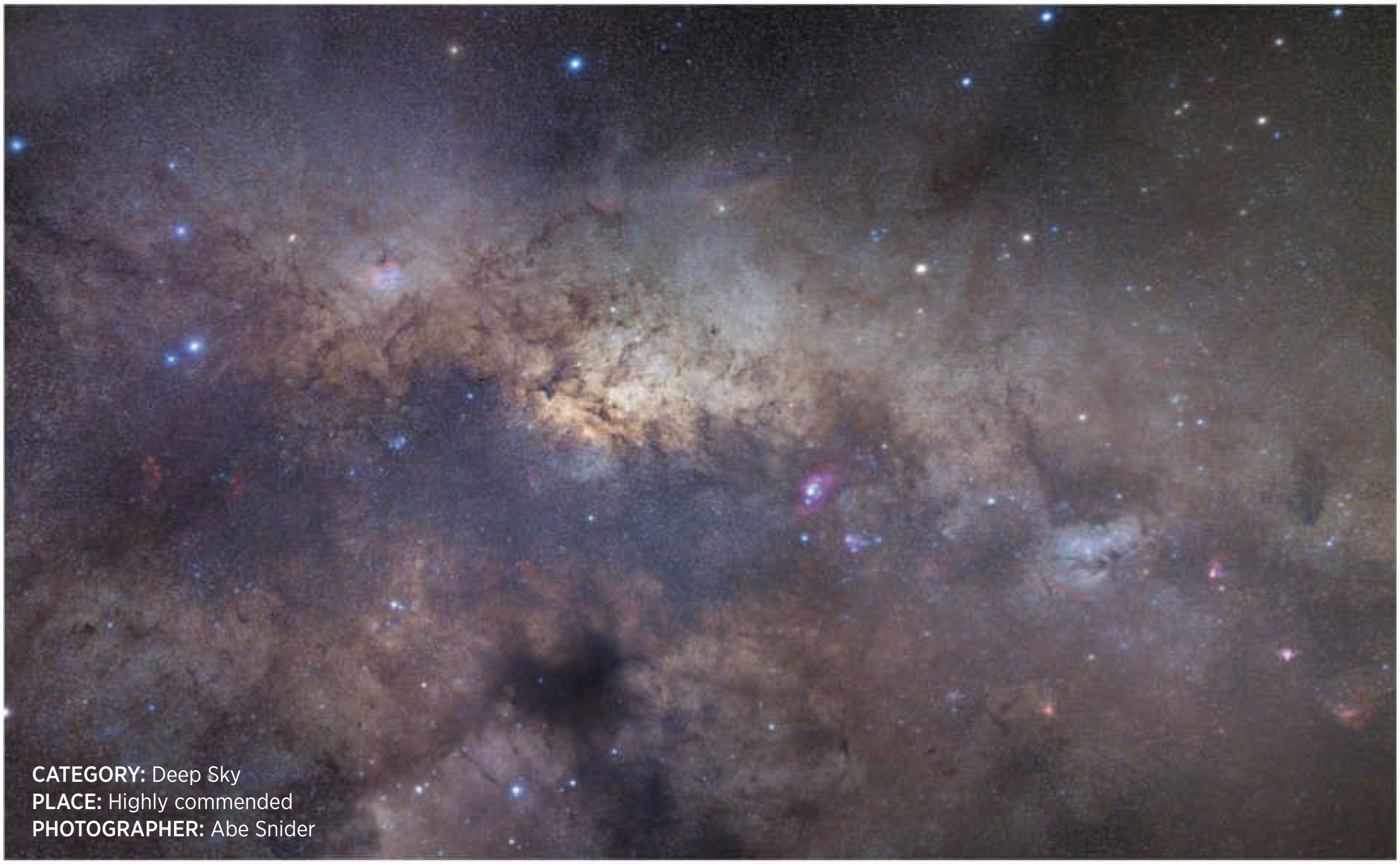


CATEGORY: Deep Sky
PLACE: Winner
PHOTOGRAPHER: Rolf Wahl Olsen

CATEGORY: Newcomers
PLACE: Winner
PHOTOGRAPHER: Andrew Given

CATEGORY: Solar System
PLACE: Winner
PHOTOGRAPHER: Mark Gee

CATEGORY: Deep Sky
PLACE: Highly commended
PHOTOGRAPHER: Raymond Collecutt



CATEGORY: Deep Sky
PLACE: Highly commended
PHOTOGRAPHER: Abe Snider

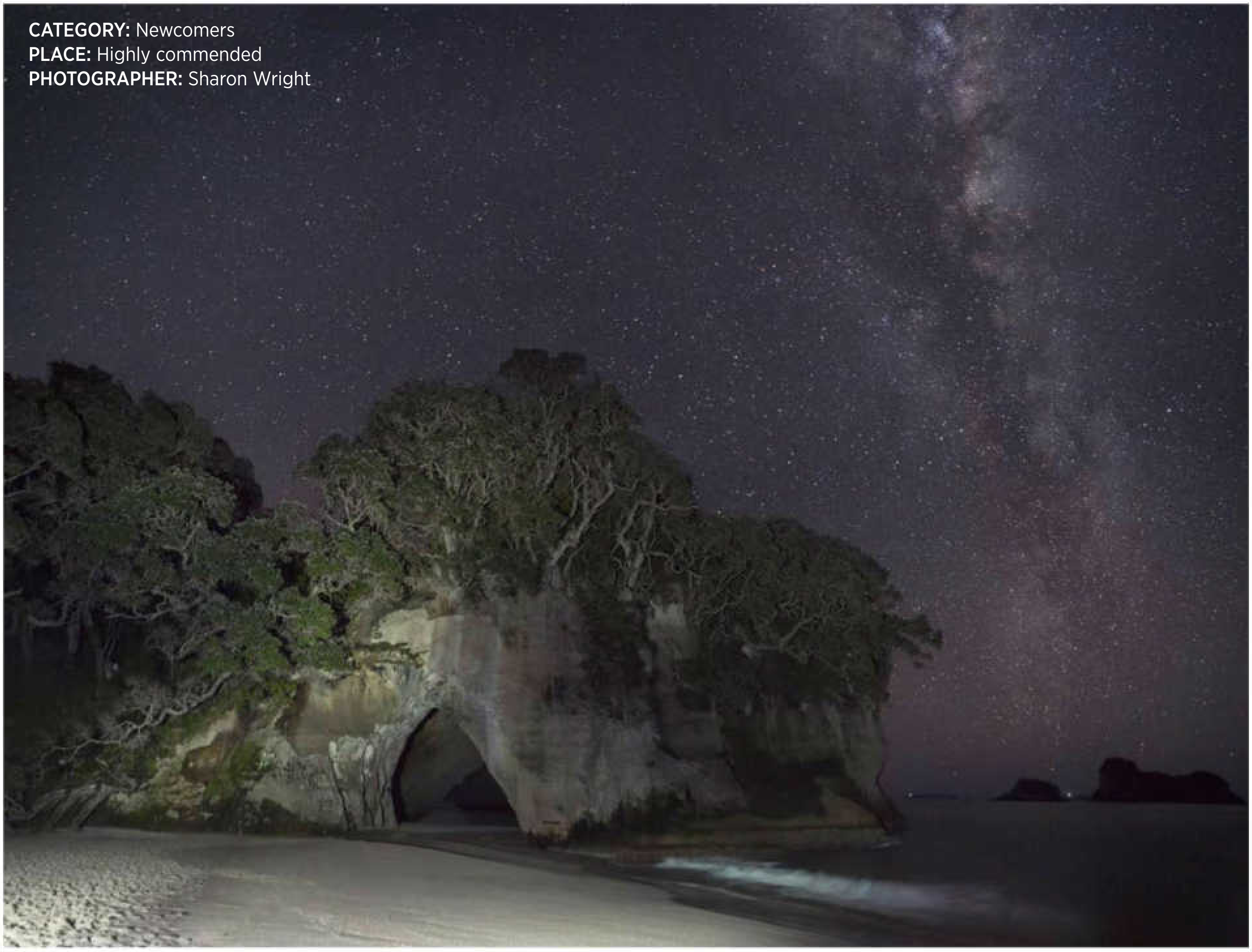
CATEGORY: Solar System
PLACE: Highly commended
PHOTOGRAPHER: Tomas Milan

CATEGORY: Solar System
PLACE: Highly commended
PHOTOGRAPHER: Sandra Whipp

CATEGORY: Artistic
PLACE: Highly commended
PHOTOGRAPHER: Adrian Hodge

CATEGORY: Artistic
PLACE: Highly commended
PHOTOGRAPHER: Les Ladbrook

CATEGORY: Newcomers
PLACE: Highly commended
PHOTOGRAPHER: Tiffany Lamb



CATEGORY: Newcomers
PLACE: Highly commended
PHOTOGRAPHER: Sharon Wright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Entering the age of General Relativity

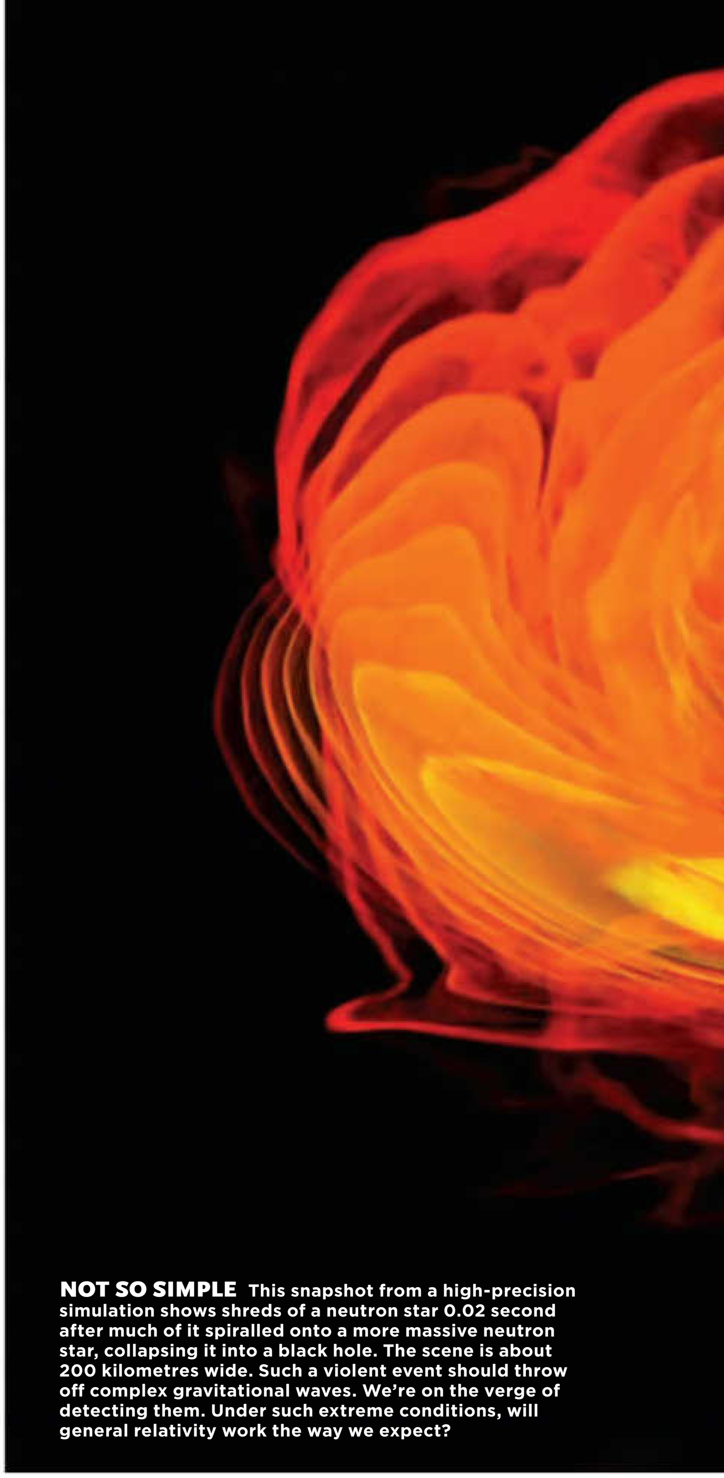
Albert Einstein published his general theory of relativity just over 100 years ago. Astronomy took 50 years to catch up. Now it's running the show.

PEDRO G. FERREIRA

The summer of 1963 was eventful by any standards. In June, US President Kennedy proclaimed *"Ich bin ein Berliner"* to the beleaguered citizens of Berlin. In July the spy Kim Philby defected to Moscow. In August Martin Luther King, Jr., declared "I have a dream" to a crowd of a quarter million. And quietly, around the swimming pool of a suburban house in Dallas, Texas, three European emigrés drank strong martinis and planned how to resurrect Einstein's general theory of relativity.

That theory is our modern theory of gravity. It took him eight hard years to figure out, but its essential formula fits on one line. Published on December 2, 1915, it transformed our understanding of what gravity is.

Einstein had abolished the gravitational 'force' proposed by Isaac Newton, which acts at a distance to pull bodies together according to their masses. Instead, space and time gained a life of their own. They form an interlocked unity, in which time is just another distance dimension except that it's multiplied by the speed of light. This unified, 4D *spacetime* becomes warped by the presence of mass. The warp alters the path that a body takes as it naturally tries (in the absence of any outside force) to continue along a straight line. This works because an object's passage through time is part of its motion through this 4D matrix (see the box on page 22).



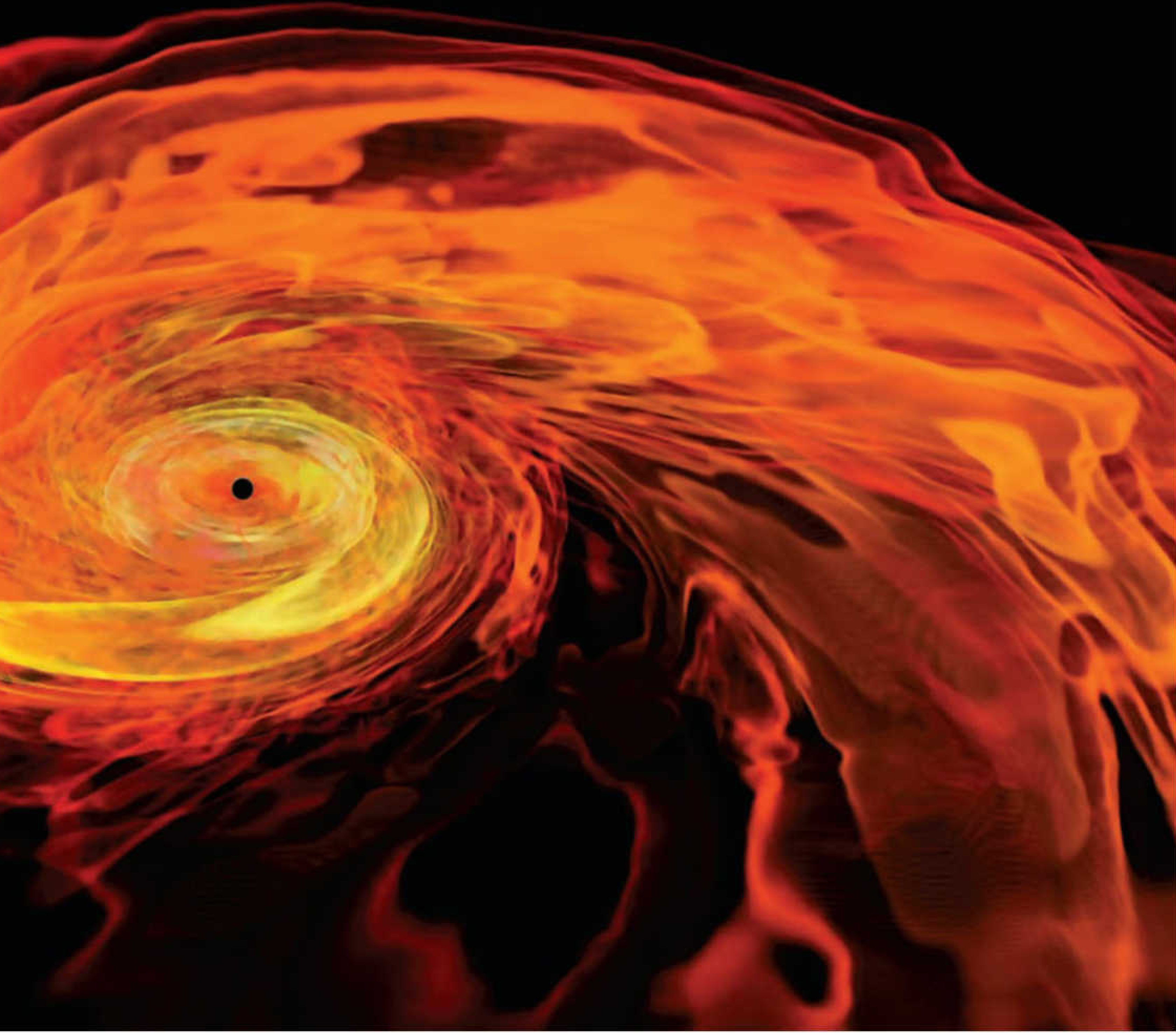
NOT SO SIMPLE This snapshot from a high-precision simulation shows shreds of a neutron star 0.02 second after much of it spiralled onto a more massive neutron star, collapsing it into a black hole. The scene is about 200 kilometres wide. Such a violent event should throw off complex gravitational waves. We're on the verge of detecting them. Under such extreme conditions, will general relativity work the way we expect?

In other words, gravity is just geometry.

General relativity explains, with fantastic precision, the dynamics of everything from pebbles to planets to galaxies. It has passed every exquisite test that has ever been thrown at it.

Moreover, as Einstein immediately realised, it predicted slightly *different* gravitational motions than Newton's theory did. The eureka moment for Einstein came in November 1915, when he found that his spacetime equations perfectly explained the slight drift of Mercury's perihelion (closest point to the Sun), something that had baffled astronomers.

Most famously, general relativity differed from Newtonian gravity in how much it predicted starlight



B. GIACOMAZZO / L. REZZOLLA / M. KOPPITZ (MAX PLANCK INSTITUTE FOR GRAVITATIONAL PHYSICS)

would bend when it passed close by the massive Sun. The total solar eclipse of 1919, when the Sun would be in front of the Hyades star cluster, offered the first great test. An eclipse expedition led by British astronomer Arthur Eddington found (just barely) that the Sun shifted the apparent positions of the background stars by Einstein's predicted amount, not Newton's. The news made world headlines and catapulted Einstein to the superstar status he's held ever since.

General relativity, in its utterly weird simplicity and power, has been called the greatest intellectual achievement of all time. It reinvented reality.

But it goes much further than explaining weak effects in the Solar System. It required spacetime on a cosmic scale — the universe itself — to be either expanding or contracting. This requirement greatly distressed Einstein because, like everyone else, he assumed that the universe as a whole was static. So it was quite a vindication when, in the late 1920s, astronomers discovered that distant galaxies are flying away from us, and the farther they are the faster they go. The cosmos was indeed expanding, quite uniformly.

General relativity also predicted black holes, points of infinite density and curvature, which are so full of paradoxes that they continue pushing the farthest frontiers of physics today.

It also predicted ripples in spacetime itself, called *gravitational waves* (see the next article). These carry

Gravity is just geometry

General relativity says that gravity is nothing more than an object's tendency, in the absence of any force on it, to follow a straight line (technically a 'geodesic') through curved 4D spacetime.

Earth bends spacetime by only a very tiny amount. So why does a ball that you toss into the air look like it follows a sharply curved arc? How can that arc be *anything like* a straight line?

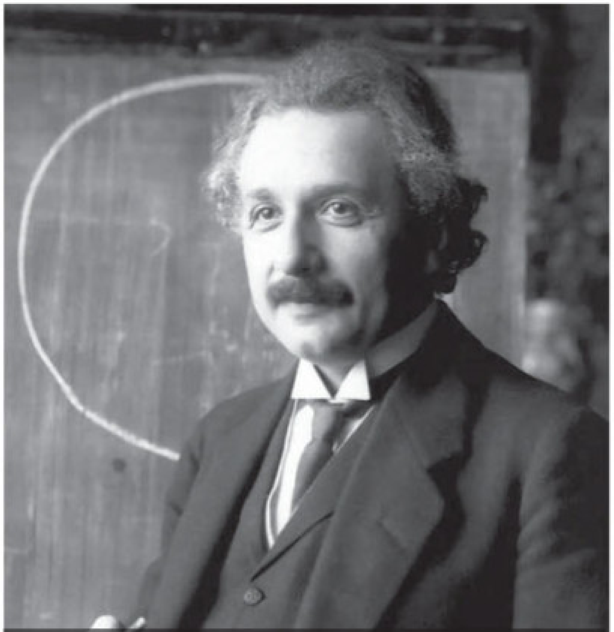
You have to think in 4D. In this perspective, the time dimension is just an extra space dimension that we're plunging through at the speed of light.

In this framework, when you toss a ball from one hand to the other, the 1 second in which the ball may be in flight is an enormous 1 light-second long: 300,000 kilometres. What looks like the ball's short, sharp arc is actually stretched way out long in this unseen dimension.

You don't see how nearly straight the line is, conforming only to the very slight warping of spacetime caused by Earth, because you're moving through the time dimension right alongside the ball.

Similarly, the weight that you feel when you hold a heavy object in curved spacetime is the *acceleration* force that you have to apply to it to continually bend it away from the straight trajectory it's trying to follow as time races forward.

— Alan MacRobert



AHEAD OF HIS TIME Albert Einstein loosed general relativity onto astronomy a half century before astronomy could do much with it, aside from checking for very tiny effects. This portrait was taken in 1921, two years after the eclipse experiment of 1919 made Einstein a superstar.

FERDINAND SCHMUTZER

energy away from violent gravitational events, where spacetime gets shaken like a rug.

But most of this remained theory on paper. Astronomical techniques were not yet up to testing general relativity's wilder predictions. Some of which were hard to believe anyway.

The 1960s revival

Fast forward half a century. Those three physicists around the pool in Texas, Alfred Schild, Engelbert Schücking and Ivor Robinson, had fallen in love with general relativity, learning their trade in the few isolated pockets where it was still studied in earnest. For the past three decades another theory, quantum mechanics, had attracted most young physicists, trying to work out its weird and wonderful practical consequences and leaving general relativity in the long grass. As a result, GR (as it was known) had acquired a reputation for being esoteric and difficult: a topic for mathematicians, not physicists. And definitely not for astronomers.

But the universe was becoming insistent. With the growth of radio astronomy after World War II, new starlike objects were discovered that pumped out exorbitant amounts of energy as radio emission and light. These 'quasi-stellar radio sources' displayed mysterious optical spectra — until Maarten Schmidt realised in 1963 that the spectrum of the brightest, 3C 273 in Virgo, was fairly normal, just unbelievably redshifted. It seemed to be more than a billion light-years away.

How could a starlike point appear so radio-powerful and optically bright from such a distance? It had to be truly massive. And when an object is both very massive and very concentrated, its gravity must be so intense that GR ought to play a dominating role.

These objects were the hook that the three Texas relativists needed to reel in the astronomers. They decided to organise a conference that would show astronomers how much they needed relativists in order to make sense of the cosmos. In December 1963 they put together the first Texas Symposium on Relativistic Astrophysics.

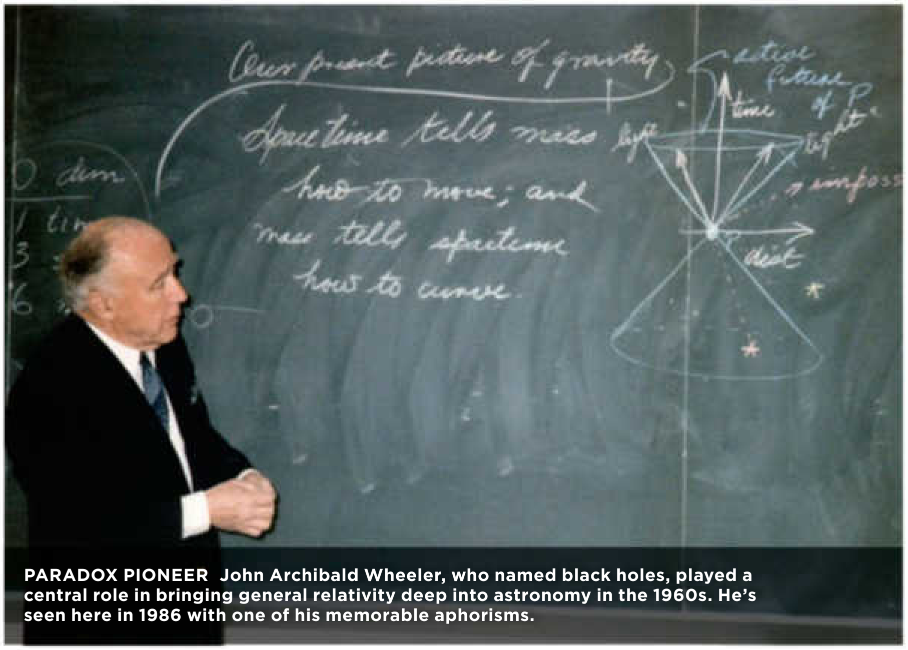
Scattered among astronomy's bigwigs at the event were a handful of pure relativists. Over three days of talks, the observations were taken apart. Fred Hoyle, from Britain, always quick to come up with new ideas, had proposed that the quasi-stellar radio sources (later shortened to *quasars*) were nothing more than stars with a million times the mass of the Sun pumping out light as they imploded. US physicist, Robert Oppenheimer, father of the atom bomb, had written one of the seminal papers on gravitational collapse in general relativity. He had shown that neutron stars (purely theoretical at the time) would, if they collected enough material, collapse to become what were later named black holes. He'd come to the symposium to

see what all the fuss was about, and, looking around at the excitement, told *Life* magazine that the meeting reminded him of the early days of quantum physics, “when all one had was confusion and lots of data.”

New Zealander Roy Kerr, one of Alfred Schild’s postdoctoral students, stood up and presented a new solution to the equations of general relativity. That summer he had found that black holes could be more complicated than physicists had thought: they could spin, dragging spacetime around with them. Kerr’s solution would play a huge role in explaining quasars as rotating black holes shredding material around them and funneling some of it into radio-emitting jets. But at the meeting his radical new result was too mathematical, too dry, and it seemed to fall on deaf ears among the astronomers. Yet, they were intrigued by what the relativists were saying. From now on the astronomers would need to pay closer attention to Einstein’s theory if they were going to understand their own data.

Astronomer Thomas Gold gave the after-dinner speech. He celebrated the beginning of a new era. About the quasars, he said, “Here we have a case that allowed one to suggest that the relativists with their sophisticated work were not only magnificent cultural ornaments but might actually be useful to science!”

The Texas relativists’ gamble had paid off. The ‘Texas Symposium’ became a biannual event (the 28th happens this December 13–18 in Geneva, still under the same name). Over the next half decade, the exotic lore of general relativity — black holes, cosmology, gravitational waves — became part and parcel of astrophysics. Today they are inextricable. And new frontiers are opening.



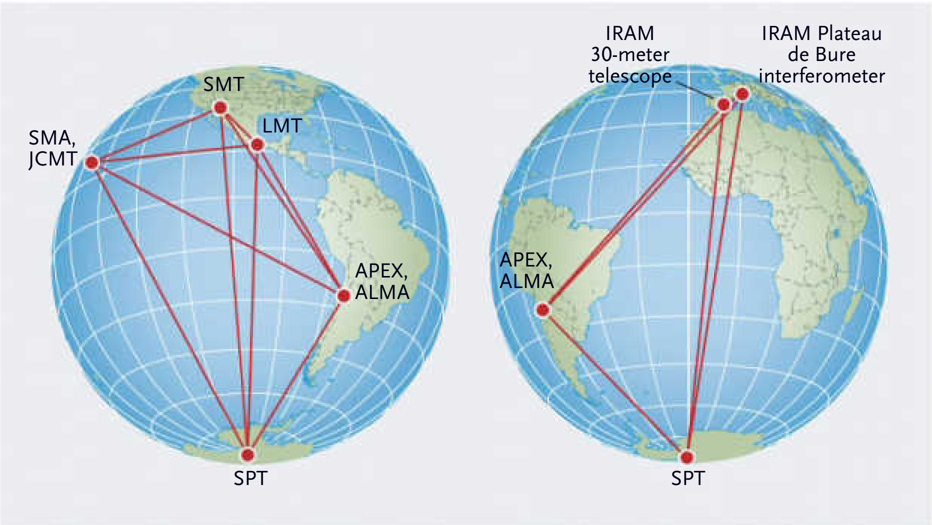
PARADOX PIONEER John Archibald Wheeler, who named black holes, played a central role in bringing general relativity deep into astronomy in the 1960s. He’s seen here in 1986 with one of his memorable aphorisms.

EMILIO SEGRE / VISUAL ARCHIVES / AMERICAN INST. OF PHYSICS / SCIENCE PHOTO LIBRARY

Next step 1: the Event Horizon Telescope

One of the speakers at that first Texas Symposium was John Archibald Wheeler. In his inimitable style he covered the blackboard with elaborate coloured drawings of spacetime, the insides of neutron stars, and aphorisms such as “the issue of the final state.” He was obsessed with Oppenheimer’s discovery that overloaded neutron stars must collapse to a mathematical point with zero size, the mass of a star and infinite density. Could that possibly be true? No infinite value ever exists for any physical quantity in nature... supposedly. Wheeler’s philosophy, he later recalled, was that “by pushing a theory to its extremes, we also find out where the cracks in its structure might be hiding.”

As I look around at astronomy today, I see this viewpoint guiding some of the great astronomical endeavours of the 21st century. For a start, black holes remain one of the bugbears of physics even as astronomers find them in abundance. It’s not just that they should have a central point of infinite curvature and density. Black holes that form by real-world processes should also surround themselves with an event horizon,



S&T: LEAH TISCIONE, SOURCE: EHT PROJECT

WORLD’S SHARPEST TELESCOPE Millimetre-wave observatories around the globe are linking up to form the Event Horizon Telescope, a giant combined telescope (‘interferometer’). Its team plans to incorporate at least nine dishes and arrays. The final network, with its very long baselines and very short operating wavelengths, should pick out features as tiny as 15 microarcseconds, sharp enough to reveal the region around the black hole at the centre of the Milky Way.

a 'surface' out of which nothing can escape, which gives fits to the theory of quantum mechanics.

In the 1960s, X-ray, radio and optical measurements made a compelling case that the X-ray source known as Cygnus X-1, a *something* orbiting a giant, 9th-magnitude B-type star 6,000 light-years away, behaved just like matter spiraling down to the event horizon of a stellar-mass black hole. Within a few more years, the explanation of quasars as hot matter jamming into much more massive black holes became well established. My theoretical colleagues now believe that the supermassive black holes at the centres of most galaxies play a crucial role in the development of the galaxies themselves. The powerful 'winds' blown out from such a hole's immediate surroundings can clear the gas right out of a galaxy and halt its star formation.

Yet we have never directly seen a black hole. Two things work against us. First of all, it is 'black' — its boundary, the event horizon, by definition emits no observable radiation. Second, black holes are very, very small. A 1-solar-mass black hole has a radius of only 2.95 kilometres. Even the 4-million-solar-mass black hole at the centre of the Milky Way, which drives the radio source known as Sagittarius A* (pronounced "A-star"), has an event horizon less than a tenth of an astronomical unit in radius — only 20% as large as Mercury's orbit. Trying to image it from Earth would be like trying to make out the width of a poppy seed in Perth from the distance of Sydney.

The Event Horizon Telescope should soon do it. The EHT is a consortium of telescopes in Chile, Europe, North America, Hawaii and Antarctica observing at wavelengths of about 1 mm... in the part of the electromagnetic spectrum between the far infrared and short microwaves. The Milky Way's dust clouds are transparent to millimetre waves, and so is the dense maelstrom around Sagittarius A* itself. So we have an unimpeded view right down to the hottest material immediately around the event horizon.

The EHT's dishes, carefully linked and exquisitely phase-matched to work together, resolve sources almost as well as a planet-size radio dish would. The long baselines, combined with the very short wavelength used, should enable the EHT to resolve Sgr A* down to a resolution of some 15 microarcseconds. That should be enough to image the black hole against the background of hot gas immediately surrounding it.

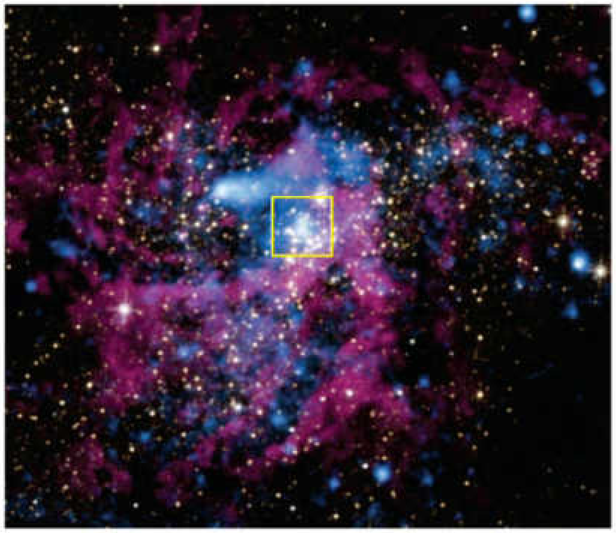
What will the EHT see? The spacetime around the event horizon should be so warped that light rays will wrap partly around it, creating an eerie, distorted apparition: a thin crown of light surrounding a silhouetted dark orb, which should be distorted and magnified by gravitational lensing to appear about five times larger than the actual event horizon.

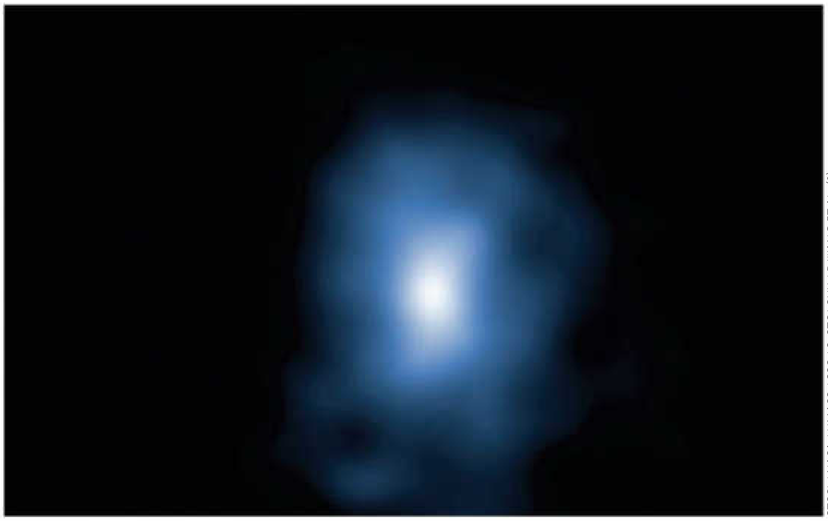
The picture the Event Horizon Telescope will take won't be sharp; the hole's magnified silhouette should appear just 10 or 15 pixels across. But for the first time, we should truly be able to see a black hole's surface pushing up through our limits of observation.

The shape of the silhouette, and how the bright crown wraps around it, will tell us whether what's there matches what GR predicts. For the first time we'll be able to explore the limits of GR directly in a place where gravity is truly extreme. This is an obvious place to look for the "cracks in the structure" that Wheeler sought.

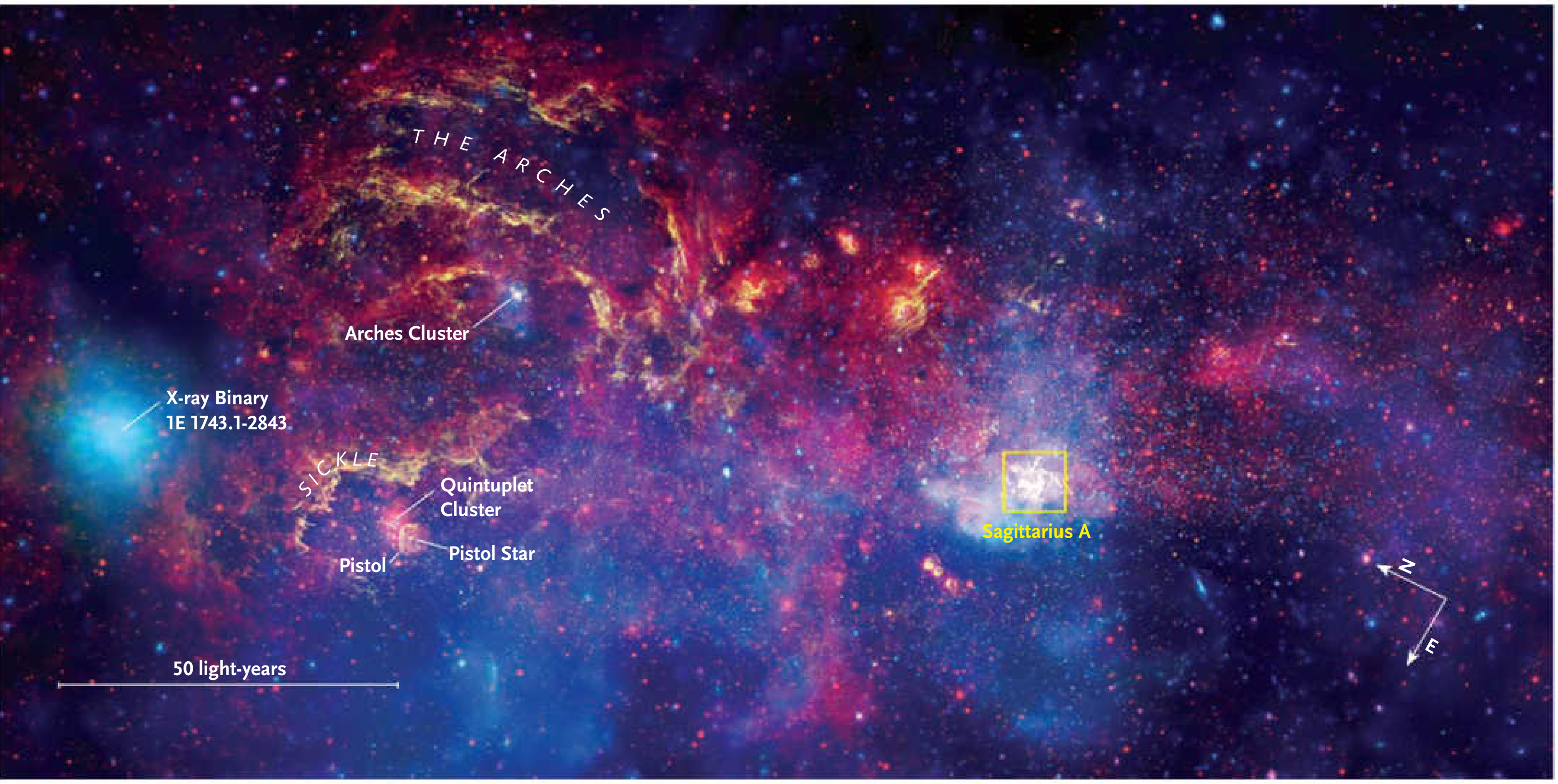
The EHT's designers also plan to observe and image the much larger black hole at the centre of the supergiant elliptical galaxy, M87. It's 2,000 times farther away, but with an estimated 6 billion solar masses, it should be 1,500 times wider. (A black hole's radius goes up in direct proportion to its mass.)

Below: **In the Milky Way's central 7.5 light-years, swirls of hydrogen (red), X-ray emitters (blue) and giant stars (emitting infrared, yellow) orbit the galaxy's surprisingly subdued central black hole.** ***Bottom:*** **An X-ray close-up of the inner 0.7 light-years around the hole. Much of the glow comes from a swarm of hot giant stars. The hole itself would be a microscopic pinprick here.**





STSCI / NASA / UMASS / SSC / S. STOLOVY / D.WANG ET AL. (3)



A ZOOM TO THE MILKY WAY'S CENTRE The view above, 245 light-years wide, encompasses many landmarks of the central Milky Way, including Sagittarius A. The view combines X-rays (blue), near-infrared hydrogen emission (yellow) and broadband mid-infrared (red). The yellow box shows the area of the frame at left.

Next step 2: gravitational wave astronomy

On a different instrumental front, the next few years should open a completely new window on the universe: gravitational wave astronomy. Just as we've used electromagnetic waves to see celestial objects since the first humans looked up, we will begin to use gravitational waves to observe some of the most cataclysmic events.

Gravitational waves are those shaken-rug ripples in spacetime. GR predicts that any accelerating mass produces them. They become significant when the masses and accelerations are extreme — for example, if two neutron stars or black holes orbit each other tightly at a fair fraction of the speed of light. We know gravitational waves are real because we see their indirect consequences. For the last 40 years we have been monitoring a particular pair of neutron stars, PSR B1913+16, discovered by Russell Hulse and Joseph Taylor (for which they won the 1993 Nobel Prize in Physics). Radio astronomers continue to track the slow, inexorable decay of the neutron stars' mutual orbit as gravitational waves carry orbital energy away — at exactly the predicted rate. This is compelling evidence, but, as with black holes, we haven't yet seen gravitational waves directly.

That's also about to change. As described in the following article, a consortium of gravitational wave detectors around the world is virtually certain to see the powerful bursts of ripples flung out when pairs of neutron stars as distant as 500 million light-years from us finally spiral into each other and merge. Even more exciting is the possibility that we will pick up the final inspirals of pairs of black holes. In this case the most outlandish predictions of general relativity, black holes and gravitational waves, would show us their most extreme behaviour combined. The signal from such an event can be precisely modelled from GR theory. Will it match what we see?

Next step 3: cosmic structure

Astronomers are also embarking on an ambitious campaign to map out, over the next two decades, the 3D positions of essentially all the large observable galaxies within our cosmic horizon — and thereby reconstruct, with unprecedented precision, the largest-scale structure of spacetime itself. By accurately understanding how galaxies are laid out to form the cosmic web, and how spacetime warps itself around the galaxy superclusters, filaments and walls, we will try to understand why, among other things, the expansion of the universe started to *accelerate* about 7 billion years ago.

Earlier than that, the expansion of the universe was slowing due to the gravitational pull of all matter on all other matter. But as space expanded and matter thinned out, some repulsive effect, discovered only in 1998, began to predominate over gravity. Is some kind of 'dark energy' doing the pushing? Or does GR itself need to be reformulated or even discarded on cosmological scales?

For now, the leading opinion is that GR remains valid but a weak repulsive force is structured into the fabric

ALL-SEEING EYE **The 8.4-metre Large Synoptic Survey Telescope (LSST) will be the most powerful survey telescope ever built. Among other things, it will map billions of galaxies back to the first era of galaxy formation, helping to determine the large-scale structure of spacetime throughout cosmic history.**

of empty space itself. That's because the force seems to work like Einstein's long-abandoned 'cosmological constant,' which he named Lambda (Λ). From what we can tell so far, this mysterious space-pressure has remained constant throughout cosmic history. That is, despite space expanding, a cubic centimetre of space always contains the same amount of it. This is in contrast to things that exist *in* space, such as particles and fields, which thin out as space expands. But is that the true picture?

The Euclid satellite, supported by the European Space Agency, should launch at the end of this decade. Euclid will map large swaths of the universe, in particular galaxies as they existed when the universe was close to half its current age (around redshift 0.8). That's about when the cosmic expansion started speeding up. We'll get a good read on how gravity worked at that time.

Euclid will harness another of GR's great predictions: *gravitational lensing*. Gravitational lensing is the bending of light rays passing a massive object; it's the effect Eddington's expedition tested with the 1919 solar eclipse. By imaging a billion very distant galaxies and analysing their slightly distorted images, we can use large-number statistics to reconstruct the characteristic warps and bends of huge regions of spacetime at various epochs.

Complementary work will happen on the ground. Moving rapidly forward is DESI, the Dark Energy Spectroscopic Instrument, which will measure redshifts and thus 3D positions for more than 30 million galaxies and quasars to redshift 3.5. But the king of all optical surveys will be the Large Synoptic Survey Telescope (LSST), now under construction in Chile. It will be the largest sky-survey camera ever, with an 8.4-metre, f/1.18 primary mirror and a 3,200-megapixel imager. It should begin work in 2023, monitoring some 37 billion stars and galaxies. Analysing the fingerprints of dark matter and dark energy in its data will be a priority.

In parallel, preparations are under way in Australia and South Africa to build the largest radio telescope ever conceived. The Square Kilometre Array (SKA) will combine radio dishes and tens of thousands of small, fixed antennas that observers can electronically sync to reconstruct signals from across the sky. The SKA will have a total collecting area of close to a square kilometre, carefully tuned to be able to look wide and deep.

A key plan for the SKA is to map early clouds of hydrogen. These should mark where and when the first galaxies formed and how they gathered to form the cosmic web. This will, again, help show how gravity and perhaps dark energy have worked through cosmic history and how spacetime has evolved over a vast range of scales.

New beginnings

Engelbert Schücking, one the Texas relativists, used to say, "An important contribution of the general theory of relativity to cosmology has been to keep out theologians by a straightforward application of tensor analysis." For many years, it also kept out astronomers. The theoretical maths were too hard and esoteric for any right-minded astronomer to waste time on.

In 2007, I was asked to be part of an advisory board to assess proposed satellite missions for the European Space Agency's Cosmic Visions program. With my colleagues, I waded through a stack of proposals for scientific missions that could cost up to US$1 billion. Teams of astronomers had thought out the most audacious and fantastic experiments they could perform in space. To my delight, almost all of the best proposals had, in one way or another, general relativity at their core.

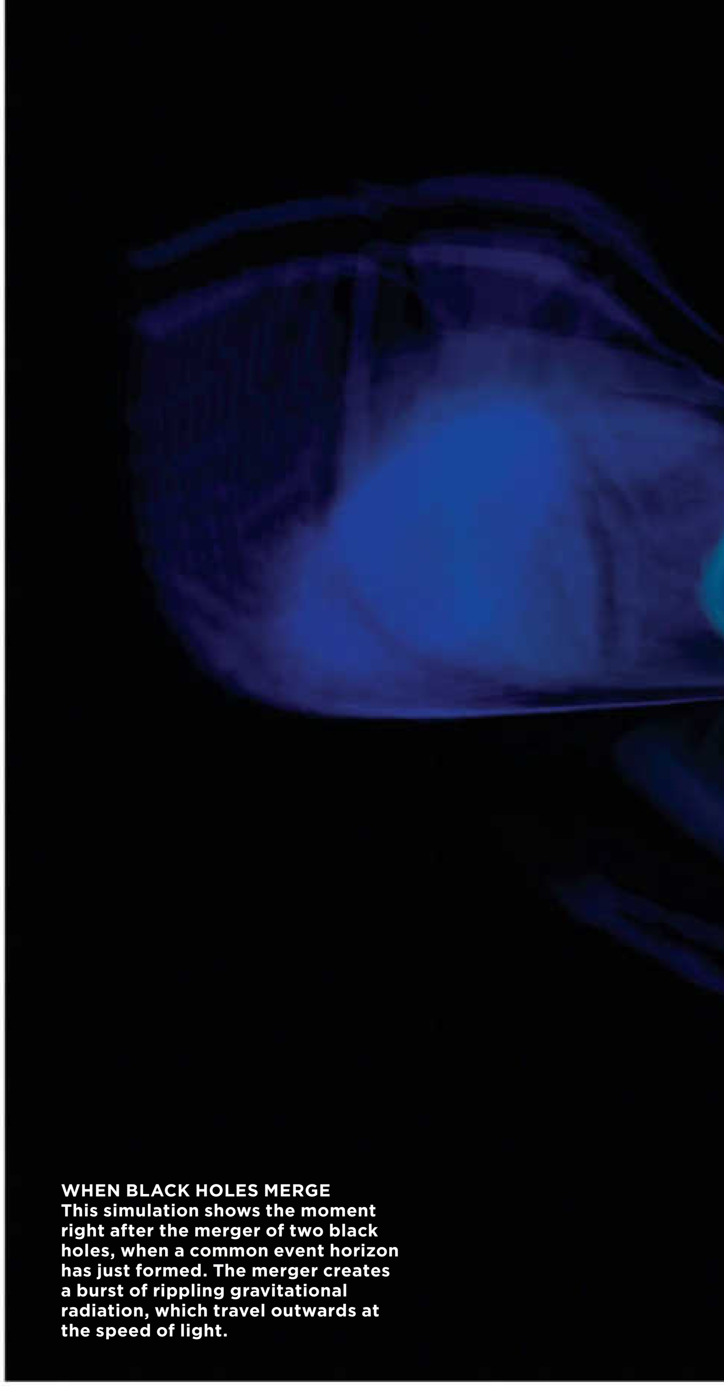
Sitting on that panel, it became clear to me that the vision of that Texas meeting, almost half a century before, was playing out at a completely new level. We are entering a new golden age in general relativity, fuelled by new developments in astronomy and astrophysics. As general relativity turns 100, it is the astronomers who are now driving its progress. ✦

Pedro G. Ferreira *is professor of astrophysics at the University of Oxford and director of the Beecroft Institute for Particle Astrophysics and Cosmology.*

Hunting the ripples in spacetime

A century after Einstein predicted their existence, scientists say they're on the verge of directly detecting gravitational waves, thereby opening a revolutionary new window on the universe.

GOVERT SCHILLING



WHEN BLACK HOLES MERGE This simulation shows the moment right after the merger of two black holes, when a common event horizon has just formed. The merger creates a burst of rippling gravitational radiation, which travel outwards at the speed of light.

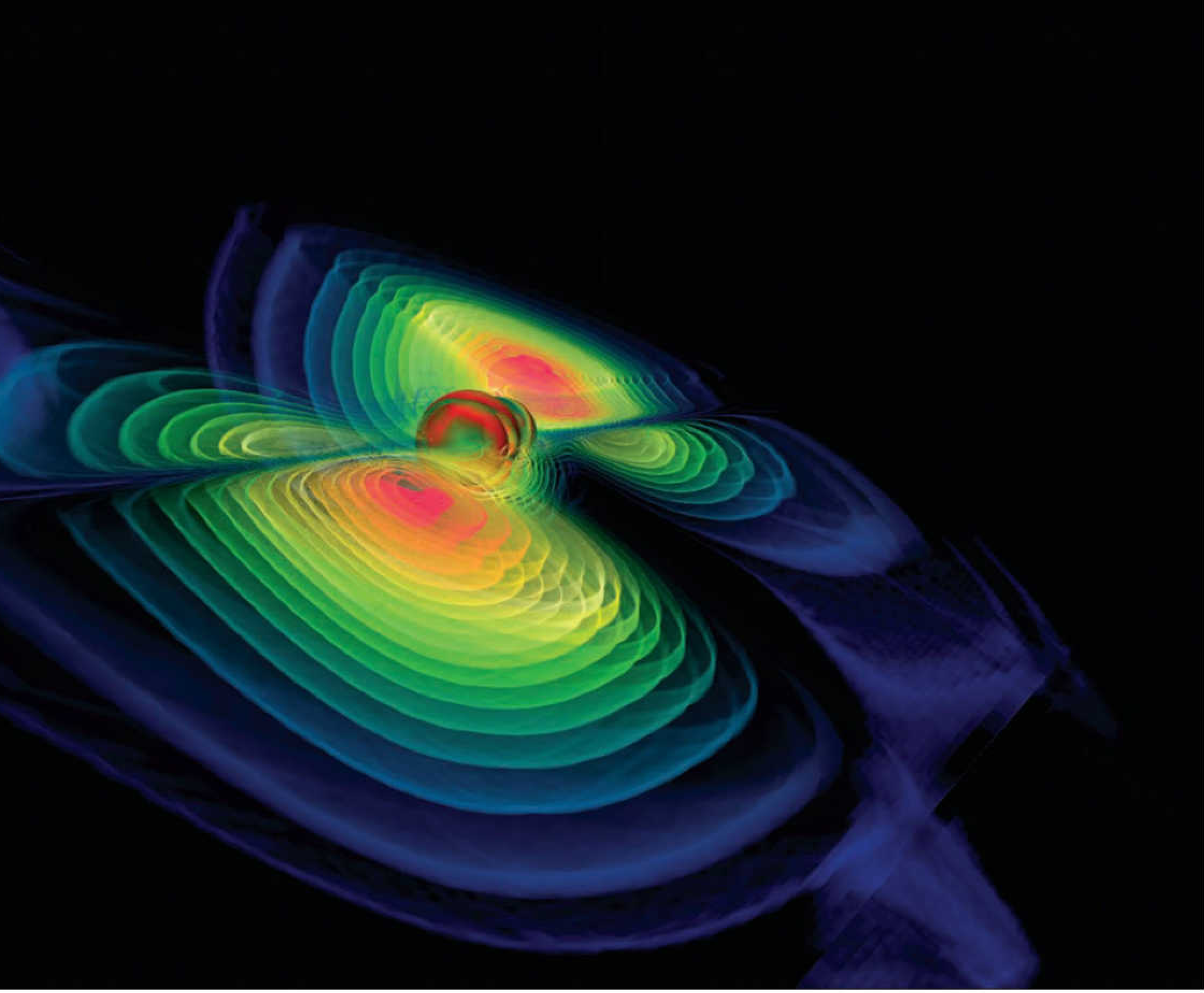
Just over 70 years ago, a plutonium reactor at the US Department of Energy's Hanford Site, north of Richland, Washington, produced the nuclear fuel for the atomic bomb that exploded over the Japanese city of Nagasaki. Now, the desolate area is home to a very different kind of physics project. Here, one of the most sensitive scientific instruments ever built is poised to detect elusive spacetime ripples from the distant universe.

Researchers have recently outfitted the Laser Interferometer Gravitational-wave Observatory (LIGO) at Hanford with powerful new lasers, ultra-stable mirrors and superfast computers for data analysis to dig out the waves' weak signal. "People will be very surprised if nothing is found," says observatory head Frederick Raab.

Other scientists are equally optimistic. At the 11th Edoardo Amaldi Conference on Gravitational Waves, held in June 2015 in Gwangju, South Korea, there was a general consensus among attendees that we can expect the first direct detection of the elusive ripples any time now. 'Listening' to these telltale cosmic waves will provide a completely new way of studying the universe, says Bernard Schutz, one of the founding directors of the Max Planck Institute for Gravitational Physics in Germany. "You can learn much more about a jungle by not just looking around, but also listening to all the sounds," he says. "Our universe is a jungle filled with mysterious creatures, and within one or two years I believe we will begin to listen to these wild animals."

The LIGO Hanford Observatory is not alone in its quest. In Livingston, Louisiana, lies an identical observatory that has also been completely refurbished over the past few years. The two sites need to work together to make a reliable detection; the first joint run occurred a few months ago. Next year, the two LIGO detectors will join forces with the European Virgo interferometer near Pisa, Italy. A smaller instrument, called Geo600, is located near Hannover, Germany. Not to be outdone, Japan is constructing a huge underground facility to search for gravitational waves, and India has plans, too.

Meanwhile, radio astronomers all over the world are teaming up to use remote pulsars — the most stable clocks in nature — as measurement tools to look for longer, slower gravitational waves than the ones these instruments will (hopefully) sense.



MAX PLANCK INST. FOR GRAVITATIONAL PHYSICS (ALBERT EINSTEIN INST.) / ZUSE INST. BERLIN / CTR FOR COMPUTATION & TECHNOLOGY AT LOUISIANA STATE UNIV.

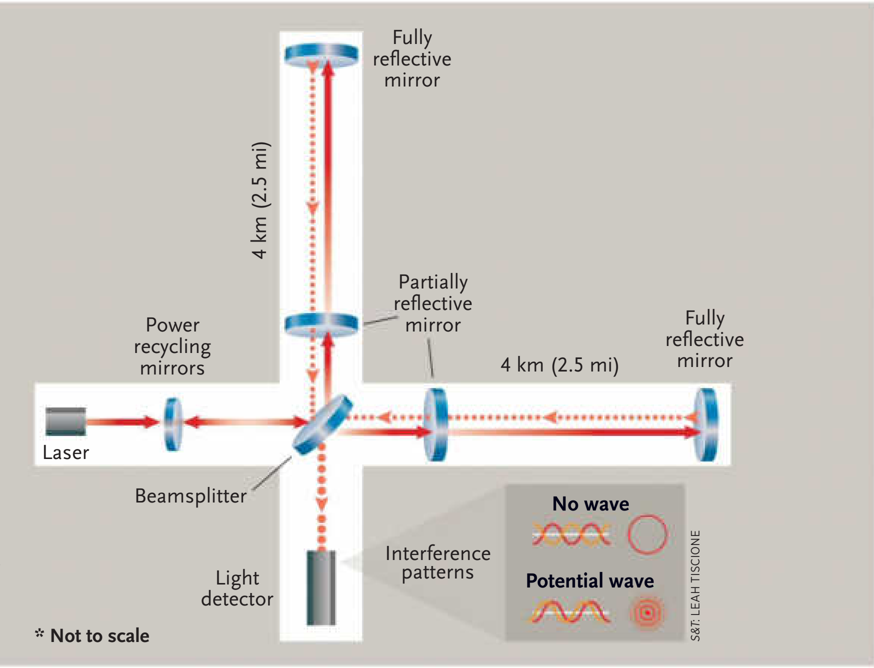
And although the first direct detection of a gravitational wave has not yet been bagged, engineers are already eyeing the future of the field. As you read this, the European LISA Pathfinder spacecraft hopefully will just have been launched from Kourou, French Guiana. LISA Pathfinder is a technology testbed mission for eLISA, the first gravitational-wave observatory in space, planned for 2034.

Making waves

Gravitational waves have nothing to do with sound. For starters, they travel at the speed of light — 300,000 kilometres per second. But they're not part of the electromagnetic spectrum either, as radio waves or X-rays are. Instead, gravitational waves are extremely small-amplitude undulations in the very fabric of spacetime. They are produced when masses accelerate. (Think exploding stars or orbiting black holes.) The bigger the mass and the stronger the acceleration, the more powerful the gravitational waves that the system 'radiates'. As they're radiated, the waves carry energy away from the system. And they're all over the universe. "They're everywhere, because space is everywhere," explains Schutz (now at Cardiff University, UK).

These spacetime swells come in a wide range of frequencies, from less than a nanohertz (corresponding to a wavelength of about 300 light-years) to a few kilohertz (a few kilometres).

Scientists can't decide when to celebrate the centenary of the prediction of gravitational waves. Albert Einstein first described them in a 1916 paper, as a consequence of his general theory of relativity. However, that original



QUALITY CHECK ***Left:*** **Team members inspect one of LIGO's partially reflective 'input' mirrors.** ***Right:*** **A schematic of LIGO. A beamsplitter sends light along two paths perpendicular to each other. Each beam then bounces between two mirrors, one of which allows a fraction of the light through. When the two transmitted beams meet and interfere, they'll cancel each other out — if the length of the path they've each travelled has remained constant. But if a gravitational wave passes through, it'll warp spacetime and change that distance, creating an interference pattern that the system will detect.**

publication contained a mathematical error, which Einstein didn't repair until 1918, when he wrote a second paper. Nevertheless, he never believed that the minuscule quiverings of spacetime might actually be detectable.

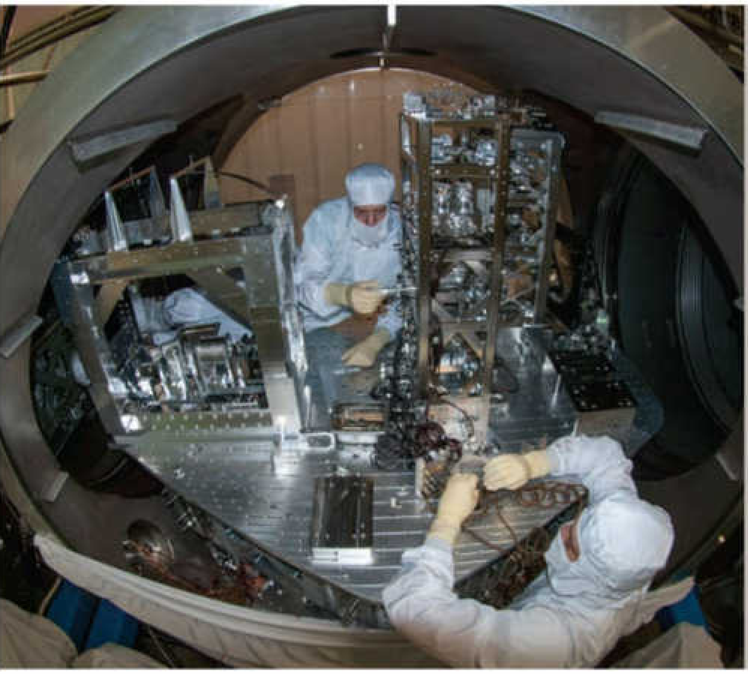
Until the mid-1970s, just a handful of physicists cared about gravitational waves — one of them being Joseph Weber (University of Maryland, College Park), who constructed several massive *resonant bar* detectors in the late 1960s and early 1970s that were supposed to start 'ringing' when a gravitational wave with the right frequency passed through. But that all changed in 1974 with the Nobel Prize-winning discovery of the now-famous binary pulsar PSR B1913+16. Within a few years, precision measurements of the pulsar's periodic Doppler shift revealed that the system was slowly shrinking: the two neutron stars are closing in on each other at 3.5 metres per year, heading for a merger in 300 million years or so. The corresponding energy loss — at present over 7 quadrillion gigawatts! — exactly matches the loss expected through the emission of gravitational waves. The message was loud and clear: gravitational waves exist. Now scientists only needed to be clever enough to directly detect them.

Mirror magic

LIGO Hanford Observatory head Frederick Raab is confident that the new facility — aptly named Advanced LIGO — is up to the task. An earlier, less sensitive pathfinder version of LIGO has been operational since 2002, both in Louisiana and Washington. But, says Raab, right from the start it was evident that two generations of detectors would be needed, to gain enough experience. "This was already part of the initial 1989 proposal to the National Science Foundation," he adds. "Initial LIGO had a small chance to maybe get one detection. That's not science, that's a stunt. You need to move forward." In fact, during eight years of operation, Initial LIGO did not detect a single gravitational wave. At a much higher sensitivity, Advanced LIGO is expected to make at least a few and maybe a few dozen detections per year.

LIGO's detection technique is pretty straightforward. Two laser beams are fired into two vacuum tunnels, each four kilometres long and at right angles to each other — it takes a 10-minute car drive to get from one end of the observatory's L to the other. The laser beams are bounced up and down the tunnels a couple of hundred times by high-precision mirrors, increasing the effective path length to many hundreds of kilometres. Then they are recombined in such a way that the two light waves cancel each other out — so long as the distance they travel doesn't change. If a powerful gravitational wave passes through, however, space is periodically stretched and squeezed, and the distance the two laser beams travel will change minutely. If that happens, the light waves won't continuously cancel each other out.

The problem is that gravitational waves are so unimaginably weak. LIGO is designed to be sensitive to the powerful waves produced when two neutron stars collide — the fate of PSR B1913+16. But the fabric of spacetime is incredibly stiff, so despite the enormous energies involved, the resulting ripples are extremely



MICHAEL FYFFE / LIGO

GRAVITY MISSION CONTROL ***Left:*** **Team members put the finishing touches on one of the power recycling mirrors, which bounce the laser beams inside LIGO back into the interferometer, boosting the power and sharpening the interference pattern.** ***Above:*** **Operations specialist Michael Fyffe took this shot of the LIGO Livingston Observatory control room. The green-numbered clock on the wall (left) shows 'atomic time,' used in GPS satellites and stations; researchers will use this clock to precisely report when an event happens.**

small. In fact, when a gravitational-wave signal from a neutron star merger 25 million light-years away passes through, the 4-kilometre separation between the end mirrors in each interferometer arm is expected to change by no more than a billionth of a nanometre a few hundred times per second. Needless to say, engineers need to isolate the mirrors perfectly from seismic noise and other terrestrial tremors.

With its more powerful lasers and improved mirror system, Advanced LIGO should be able to detect gravitational waves from neutron star mergers out to an extraordinary distance of some 500 million light-years — a big enough volume of space to catch at least a couple of events per year from the million or so galaxies in that volume. Scientists need a simultaneous detection by both LIGO observatories to rule out local noise sources. Teaming up with Virgo and Geo600 in Europe — and, in the future, the similar facilities in Japan and India — will make it possible to broadly localise the source of the gravitational waves on the sky, enabling wide-angle optical telescopes to quickly carry out follow-up observations, like paparazzi photographers responding to sounds, voices or other audible cues.

"That would be something like a cosmic version of Where's Waldo," Samaya Nissanke (Radboud University, the Netherlands) told the Edoardo Amaldi Conference in Gwangju. "But we're ready; an optical hunt is possible today."

Taking the pulse

But will interferometers such as LIGO really be the first to catch a wave? Maybe not. Radio astronomers are pursuing a completely different way to detect them, using pulsars in our Milky Way Galaxy. If space is periodically stretched and squeezed, the argument goes, this should show up as minute variations in the pulse arrival times, because the pulsars' distances are periodically changing. By monitoring a number of pulsars at known distances spread across the sky, it should be possible to spot a passing wave. In a sense, it's comparable to using the bobbing motions of floats on a pond to discover waves on the water's surface. Sounds easy, and relatively cheap, too.

Of course, it's not as straightforward as it seems. There are loads of other effects that could subtly influence pulse arrival times, explains Ryan Shannon (CSIRO, Australia), all of which astronomers have to fully understand and compensate for. Moreover, pulsar distances are generally not known precisely enough to accurately apply the technique. Still, by measuring a large ensemble of pulsars, and by carrying out a complicated statistical analysis, the pulsar timing array (PTA) technique has a lot of potential. Astrophysicists are excited by the prospects: while LIGO-like interferometers are sensitive to the high-frequency gravitational waves from merging neutron stars (a few hundred hertz), PTAs would detect the long-wavelength, very low-frequency waves from binary black holes in distant galaxies.

In fact, says Shannon, the fact that a decade-long data set from the Australian Parkes Pulsar Timing Array (PPTA, published in 2013) didn't show any evidence for those nanohertz waves has already ruled out many existing models that predict the frequency of merging galaxies and coalescing supermassive black holes. Meanwhile, similar programs are now in progress in Europe (European Pulsar Timing Array, EPTA) and the

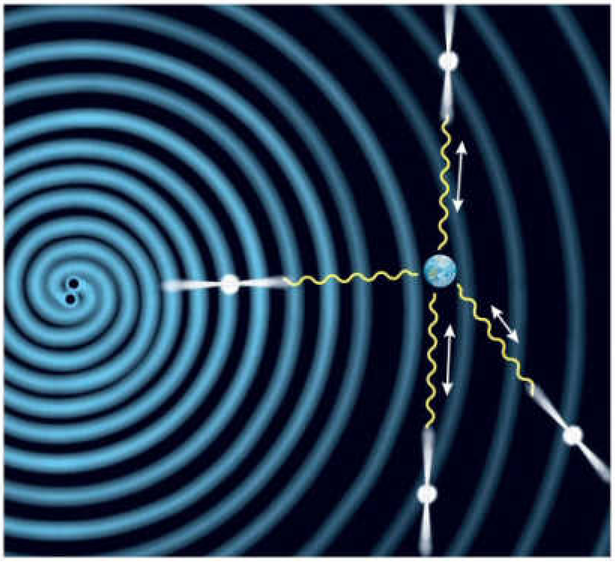
United States (North American Nanohertz Observatory for Gravitational Waves, NANOGrav); together the three constitute the International Pulsar Timing Array (IPTA). The hope is that a firm, statistically significant detection will be made soon. Says Pablo Rosado (Swinburne University of Technology, Melbourne): "With so many models already ruled out by our current non-detection, we're starting to get worried."

Frankly, you can't blame gravitational-wave scientists for being at least a *bit* worried. Between 2002 and 2010, Initial LIGO did not detect a single neutron star merger within 50 million light-years, although that would've been a lucky catch. But searches for long-duration 'continuous wave signals' — from known X-ray binary stars such Scorpius X-1 or from young, rapidly spinning neutron stars that are not perfectly spherical — also have come up empty. PTAs: nothing yet. Advanced LIGO — well, you would've seen front-page headlines if there had been a detection by now.

Still, confidence abounds. "If there are no signals out there, how would you explain the binary pulsar?" asks Raab. And in Gwangju, a self-assured Deirdre Shoemaker (Georgia Institute of Technology) told her audience that "the first gravitational-wave signal that we're going to detect has already passed Proxima Centauri." In other words: we'll hit the jackpot before 2019.

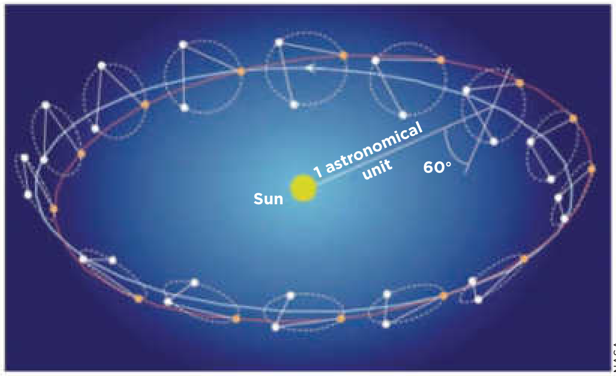
Discovery space

OK, so let's assume that we're indeed on the doorstep of a revolutionary discovery — the confirmation of a century-old prediction of general relativity, and the opening up of a new window on the high-energy universe. Then what?



S&T: LEAH TISCIONE

HOW A PULSAR TIMING ARRAY WORKS Pulsars broadcast regular 'beats' as their radiation jets spin in and out of view. The arrival time of those beats depends on the distance between us and the pulsar. Normally, that distance doesn't suddenly change, and neither does the pulse's arrival time. But when gravitational waves pass between us and a pulsar, they will slightly stretch and squeeze the space perpendicular to their direction of motion. The pulsar's distance thus oscillates, making some pulses arrive earlier and others later than expected.



NASA

ELISA ORBIT ESA's eLISA mission will comprise three spacecraft flying in a triangle about a million kilometres on a side. Tilted 60° to the ecliptic, the triangle formation will cartwheel around the Sun behind Earth in our planet's orbit. Free-falling masses inside each spacecraft will hover undisturbed by forces other than gravitation.

Fast forward two decades. Somewhere on the planet — most likely in Europe — construction workers are digging huge tunnels to house the Einstein Telescope, a triangular underground super-LIGO with interferometer arms 10 kilometres long and capable of detecting neutron star mergers out to billions of light-years. Meanwhile, the European Space Agency (ESA) is preparing for the launch of eLISA, the first space-born gravitational-wave observatory. "eLISA will cover the millihertz frequency range, which cannot be studied from the ground because of seismic noise," says Jonathan Gair (University of Cambridge, UK). The observatory will detect gravitational waves from relatively lightweight supermassive black holes (tens of thousands to tens of millions of solar masses) in the cores of galaxies, from thousands of compact binary stars in the Milky Way, and maybe even from cosmological sources like cosmic strings — hypothetical defects in spacetime produced in the newborn universe.

The eLISA mission will use three separate spacecraft floating in a huge triangle formation. Laser beams will fire, reflect and recombine across distances of a million kilometres to create a giant interferometer. The LISA Pathfinder mission, due for launch before year's end, will test all necessary eLISA technologies using two test masses free-floating some 40 centimetres apart within a single hollow spacecraft.

Twenty years from now, LISA Pathfinder will be history, just as Einstein's doubts about the existence of gravitational waves, the fuss around Weber's claims of measuring the waves with his bar detectors, and, hopefully, the worrisome non-detections by pulsar timing arrays. By then, gravitational-wave astronomy should have evolved into a rich and fruitful discipline, shedding light on a wide variety of astronomical objects and processes, from the Big Bang and galaxy mergers to supernova explosions, gamma-ray bursts and compact binary stars. Who would have imagined that back in 1915? ✦

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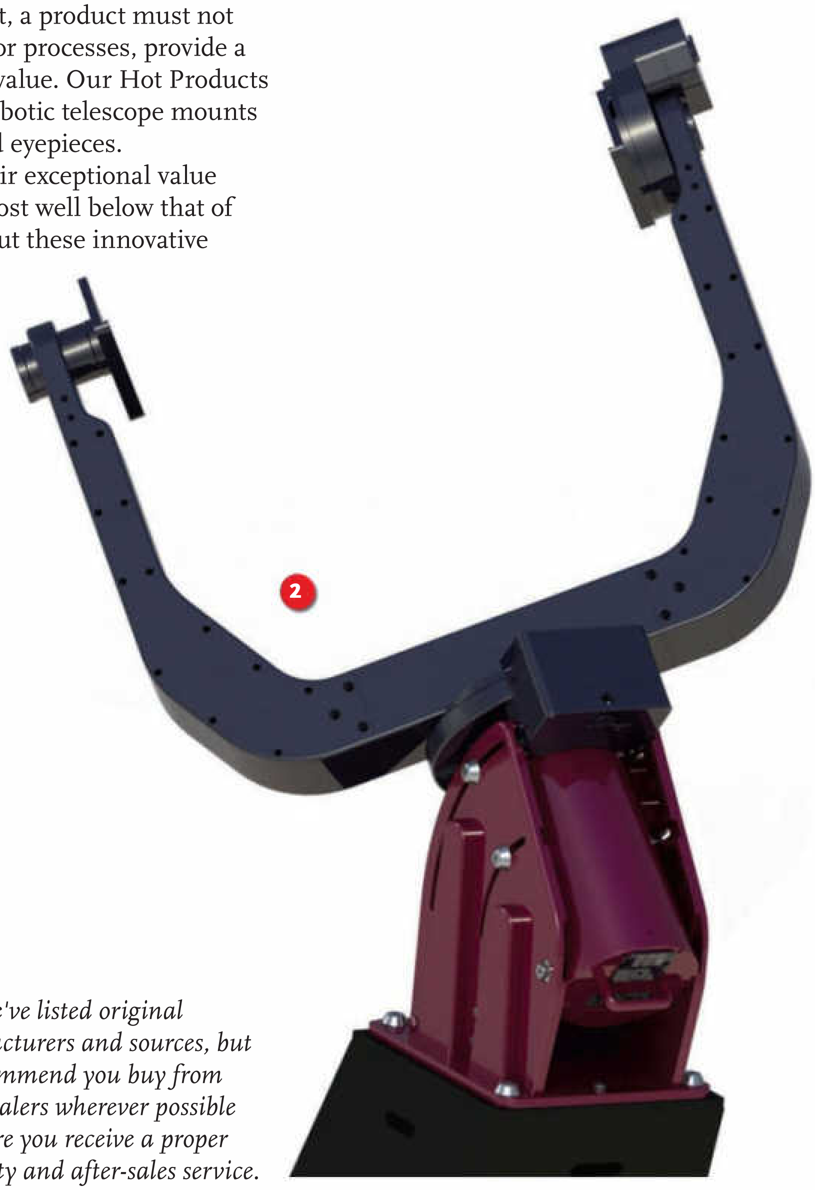
HOT Products for 2016

Each year we scour the marketplace searching for what we consider to be some of the year's most exciting new products. To make our list, a product must not only be new but should also introduce new technologies or processes, provide a solution to an old problem, or simply deliver exceptional value. Our Hot Products list for 2016 includes a variety of gadgets ranging from robotic telescope mounts to cameras, observing aids, and, of course, telescopes and eyepieces.

This year many products caught our eye because of their exceptional value — equipment that offers features and performance at a cost well below that of similar items in the past. We hope you enjoy reading about these innovative products that piqued our interest as of late 2015.



MORPHEUS EYEPIECES

Baader Planetarium

1

An eyepiece design that caught our attention this year is the Morpheus series from Baader Planetarium. These dual-format (1¼- and 2-inch) oculars are available in 4.5-, 6.5-, 9, 12.5, 14-, and 17.5-mm focal lengths that boast a generous 76° apparent field. Additional features in the series include glow-in-the-dark markings and T-threads beneath the rubber eyeguard.

PARAMOUNT TAURUS

Software Bisque

2

With their ability to track the sky uninterrupted from horizon to horizon without having to 'flip' the telescope at the meridian, fork mounts have long been a favourite of astrophotographers. The Paramount Taurus, the first-ever fork mount from Software Bisque, is designed for today's astrographs in the 0.5- to 0.6-metre range and weighing up to 180 kg. It has all of the robotics and advanced features available throughout the storied Paramount line of German equatorial mounts.

NB: We've listed original manufacturers and sources, but we recommend you buy from local dealers wherever possible to ensure you receive a proper warranty and after-sales service.

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3 QUATTRO IMAGING NEWTONIANS

Sky-Watcher

As with visual observing, Newtonian reflectors have traditionally delivered the biggest bang for the buck when it comes to astrophotography. Coupled with the latest coma correctors, Newtonians deliver deep-sky imaging performance on par with premium astrographs. And this line of 20-, 25- and 30-cm f/4 Imaging Newtonians offers outstanding value.

4 ZWO ASI224MC CAMERA ZWO

Built around Sony's IMX224 digital sensor with 3.75-micron pixels and extended near-infrared sensitivity, this 1.2-megapixel, colour, USB 3.0 camera has quickly become the *camera de jour* for planetary imagers. We've been especially wowed by images of the gas giants Jupiter, Saturn, Uranus and Neptune made with the ASI224MC shooting through ZWO's new CH4 methane-band filter, which, like the camera, is an exceptional value.

5 LOW-COST BAHTINOV FOCUSING MASKS

Farpoint Astronomical Research

Designed for astrophotographers shooting with conventional lenses on DSLR cameras, these plastic focusing masks will ensure your images have pinpoint stars. Masks are available for lenses that accept standard thread-in filters from 52- to 82-millimetre diameters. We've seen comparable products costing 4 to 5 times more.

6 SPECTRA-L200

JTW Astronomy

Spectroscopy is a small but growing aspect of amateur astronomy. The new Spectra-L200 compact spectrograph delivers a level of performance similar to units costing considerably more. It works with a wide range of astronomical CCD cameras and autoguiders.

VLB LASER COLLIMATOR ACCESSORY 7

Howie Glatter (collimator.com)

Laser collimators are great for aligning telescope optics, but as anyone who has used one knows, sometimes the laser beam's brightness can be so overpowering that it makes alignment difficult. Enter Howie Glatter's variable-laser-brightness accessory. This modified battery cap/switch fits all past and present Glatter laser collimators and lets you tune the laser's brightness to an appropriate level for the task at hand.

TRUSS-TUBE DOBSONIANS 8

Explore Scientific

This trio of well-designed Dobsonians promises to pack a lot of observing pleasure into scopes that break down into easily managed pieces for transport and storage, thanks in part to sub-assemblies that nest within larger components. The line includes 25- and 30-cm f/5 models and a 40-cm f/4.5.

ULTRASTAR 9

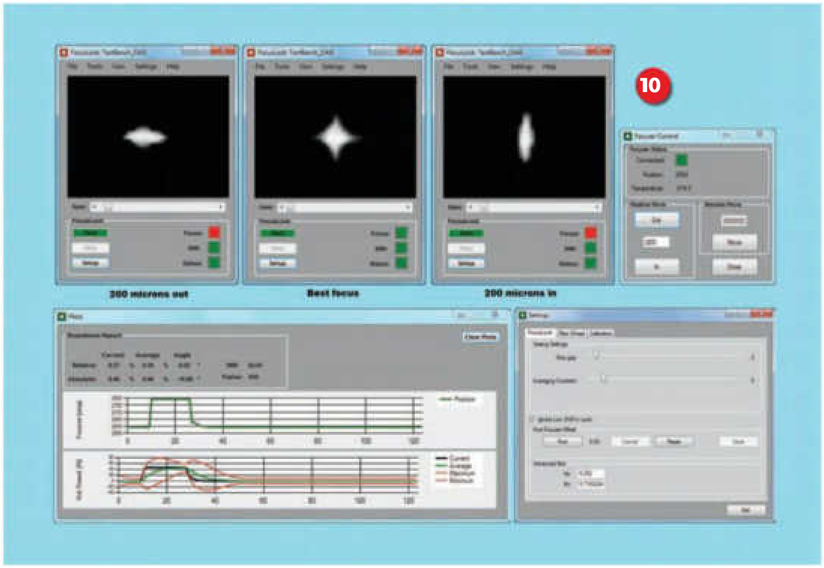
Starlight Xpress

Starlight Xpress has a well-deserved reputation for its line of high-quality, compact autoguiders that slip into standard 1¼-inch focusers. The newest addition to the line, Ultrastar uses Sony's 1.45-megapixel ICX825 CCD with an impressive 75% quantum efficiency and a generous 8.98-by-6.71-mm imaging area. The low-noise chip enables the camera to double as a deep-sky imager.

SHARPLOCK SOFTWARE 10

Innovations Foresight

Anyone doing imaging with Innovations Foresight's ONAG on-axis guider can now shoot pictures with autofocusing maintained throughout the exposure. Unlike other systems that rely on predetermined focus settings, *SharpLock* software monitors a real-time star image in the field being photographed and issues corrections to any ASCOM-compliant focuser.



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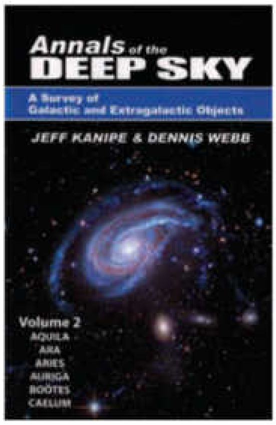

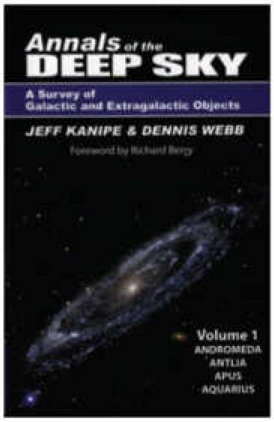

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11 DELITE EYEPIECES

Tele Vue

While the DeLite name is a nod to these eyepieces' origins as smaller and more economical versions of Tele Vue's highly acclaimed Delos eyepieces, the name also describes observers' reactions to using them. The DeLites feature long eye relief, 62° apparent fields, and the superb optical performance we've come to expect from Tele Vue.

12 ASTRO-TECH ED TRIPLET REFRACTORS

Astronomics

Every year brings a wave of new refractors to the astronomy market, but these models in the Astro-Tech line stand out for their feature/cost ratio. Having three-element objectives made with extra-low dispersion glass, these 80-mm f/6, 115- and 130-mm f/7 refractors are priced well below the competition. All come with a 2-inch, dual-speed focuser, 2-inch dielectric-coated mirror diagonal, tube rings and a Vixen-style dovetail bar.

13 IPANO CAMERA PLATFORM

iOptron

This programmable, robotic camera platform is designed for photographers shooting the new breed of large-scale, gigapixel panoramas, but it is equally well suited to astrophotographers seeking to assemble night-sky time-lapse sequences and panoramas from their DSLR frames. It will carry cameras and lenses weighing up to 5 kg and is powered by internal rechargeable batteries.

14 ANNALS OF THE DEEP SKY

Willmann-Bell

Annals of the Deep Sky is destined to become an observing guide that ranks among such 19th-century classics as Smyth's *Cycle of Celestial Objects* and Webb's *Celestial Objects for Common Telescopes.* Billed by some as the next-generation *Celestial Handbook* (Robert Burnham's 20th-century opus), *Annals* is reviewed in this issue, page 72. Authors Jeff Kanipe and Dennis Webb go far beyond what is seen in the eyepiece and cover the history, lore and scientific background of the objects they write about. The first two volumes of *Annals* are out, and more are on the way.

GEMINI FOCUSING ROTATOR 15

Optec

High-end imaging systems often include a motorised focuser and a camera rotator to help compose images and locate suitable guide stars. This ASCOM-compliant combination focuser/rotator from Optec is noteworthy for its robust construction, generous 95-mm aperture, and extremely low profile, requiring just 57-mm of back focus in the imaging train, making it a particularly useful accessory for remote imagers.

INFINITY 90 REFRACTOR 16

Meade Instruments

We're always on the lookout for quality, entry-level telescopes within the price range of beginning amateur astronomers. As our Test Report in this issue explains, this 90-mm f/6.7 refractor fills the bill, especially considering that it comes ready to use with a sturdy tripod and a good selection of accessories well suited to viewing the Moon, planets, brighter deep-sky objects and terrestrial scenes.

PRISM+ SOFTWARE 17

Prism America

Long an extremely popular program in France, *Prism+* is now available with a newly revamped English-language interface. The richly featured program does everything from help plan observations to controlling telescopes, cameras and complete observatories. And once your observations are done, *Prism+* will help process and analyse the data. There are algorithms for doing astrometry, photometry, image blinking, supernova searches and much more.

SOLAR OBSERVING HOOD 18

TeleGizmos

Simple, effective, and downright cool in more ways than one, this dual-layer cover has a polyethylene outer surface that reflects the Sun's heat and an opaque inner layer that provides a darkened environment for solar observers and photographers. It is especially helpful for those people working with hydrogen-alpha scopes.

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19 TRUSS-TUBE IMAGING NEWTONIANS

Astronomics

As alluded to earlier, Newtonian reflectors are experiencing a revival for deep-sky astrophotography thanks to modern, high-performance coma correctors. These 25- and 30-cm f/4 Newtonians are designed for imaging. Each features a carbon-fibre truss-tube assembly for focus stability in changing temperatures, quartz mirrors with enhanced-aluminium coatings offering 96% reflectivity, and a pair of Losmandy-style dovetail mounting bars.

20 MINI LIGHTBRIDGE

Meade Instruments

Meade's popular line of LightBridge Dobsonian reflectors is shrinking, but only in terms of aperture and price! Three new tabletop models, with parabolic primary mirror apertures of 82-, 114- and 130-mm, promise to put a lot of observing pleasure in a compact, portable and easy-to-use package. Each features a 1¼-inch rack-and-pinion focuser, a red-dot finder, and two eyepieces. And there's also Meade's reputation for quality.

21 NIKON D810A CAMERA

Nikon

Nikon has released its first-ever DSLR made especially for the astronomy market. Based on its flagship 'prosumer' model, the 36.3-megapixel D810A has extended red sensitivity for capturing the astronomically important hydrogen-alpha wavelength. Special features such as low-light live preview for focusing, and pre-set exposures up to 15 minutes, are just two of the new astrophotography-friendly aspects of the camera.

22 IOPTRON CEM25-EC

iOptron

This updated version of the ZEQ25 equatorial mount is now available with high-resolution encoders and new electronics that reduce the drive's periodic error to less than 0.5 arcsecond. It has the potential to eliminate the need for guiding with modest-focal-length setups and multi-minute exposures, making it a possible game changer for some types of astrophotography.

Gary Seronik
Binocular Highlight

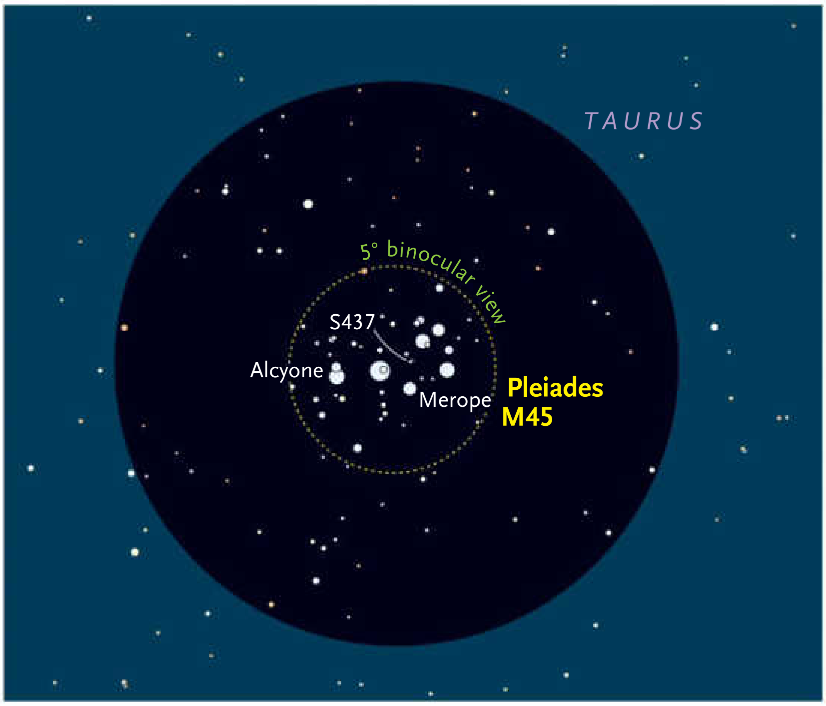
The Splendid Pleiades

If I had to choose just one deep sky object to demonstrate the appeal of binocular astronomy, it would probably be the Pleiades (M45) in Taurus. The cluster has two things going for it. First, you can see it without optical aid, which means even casual stargazers are drawn to it. Second, the Pleiades are visually impressive through any binocular under a wide range of sky conditions. You don't need pristine country skies to appreciate the splendour of this deep sky wonder.

The Pleiades have inspired countless observers. In his 1965 memoir, Starlight Nights, famed variable star observer and comet hunter Leslie Peltier recounts an early childhood view of the cluster and describes it as his "first meeting with the stars." Keen-eyed observer Stephen James O'Meara poetically likens the sight to "a forest of starlight bathed in moonlit mist."

Part of the cluster's visual appeal is its clutch of bright stars. These are the so-called Seven Sisters, though most naked-eye observers can clearly perceive only five. The stellar quintet ranges in brightness from magnitude 2.8 (Alcyone) to 4.1 (Merope). Through binoculars, the sister stars are joined by a large gathering of fainter siblings. My eye is always drawn to a neat arc of five, 7th-magnitude stars. And if you have 10× binos, try for the difficult 8th-magnitude double star, South 437, situated near the middle.

The Pleiades are one of a handful of deep sky treasures best appreciated with binoculars. The field of view provided by many telescopes is too restrictive to contain the entire cluster and its surroundings. ✦



USING THE STAR CHART

WHEN

Early December	1 a.m.
Late December	Midnight
Early January	11 p.m.
Late January	10 p.m.

These are daylight saving times. Subtract one hour if daylight saving is not applicable.

HOW

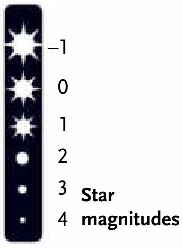
Go outside within an hour or so of a time listed above. Hold the map out in front of you and turn it around so the label for the direction you're facing (such as west or northeast) is right-side up. The curved edge represents the horizon, and the stars above it on the map now match the stars in front of you in the sky. The centre of the map is the zenith, the point in the sky directly overhead.

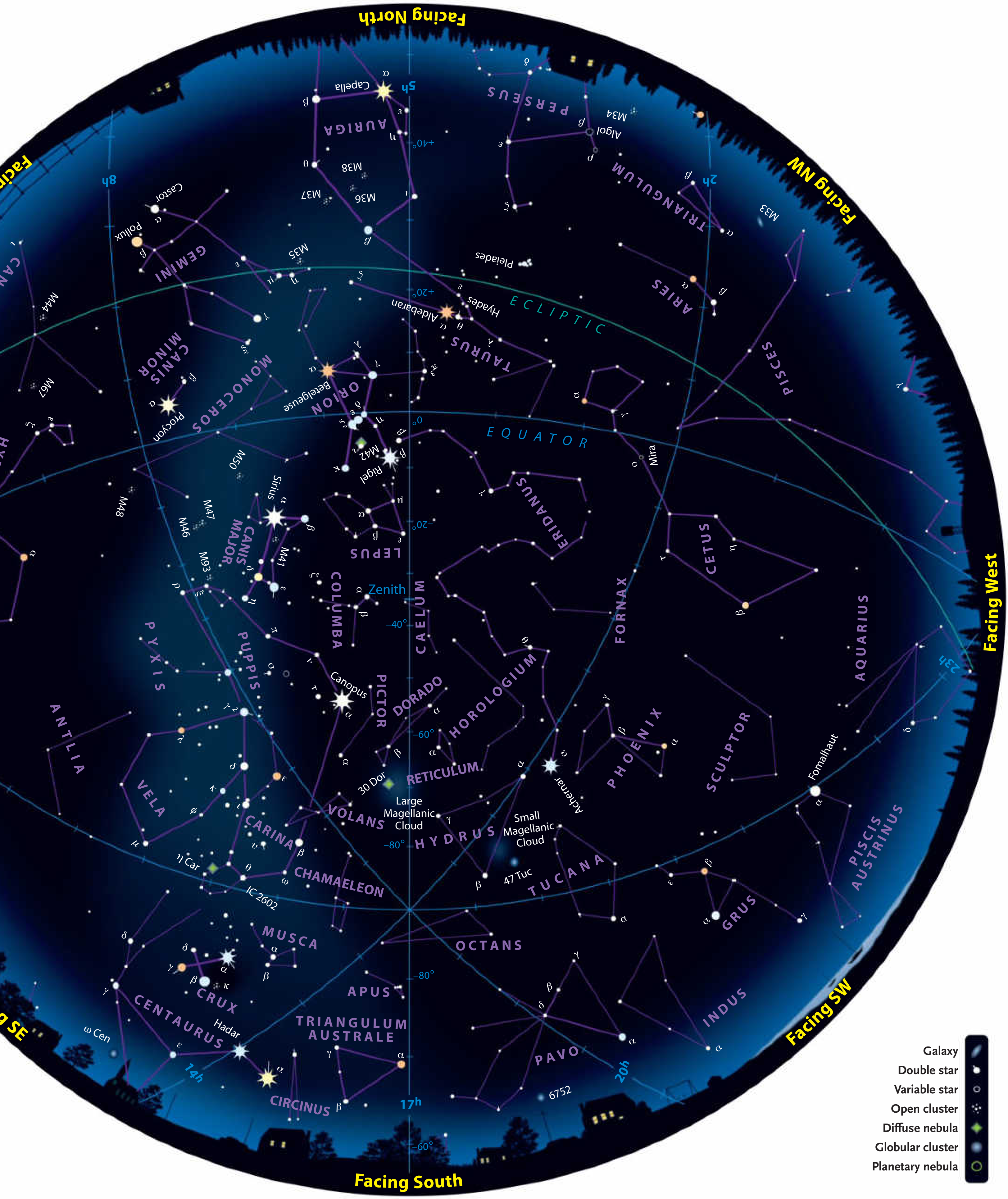
FOR EXAMPLE: Turn the map around so the label "Facing NE" is right-side up. About halfway from there to the map's centre is the bright star Procyon. Go out and look northeast halfway from horizontal to straight up. There's Procyon!

NOTE: The map is plotted for 35° south latitude (for example, Sydney, Buenos Aires, Cape Town). If you're far north of there, stars in the northern part of the sky will be higher and stars in the south lower. Far south of 35° the reverse is true.

ONLINE

You can get a sky chart customised for your location at any time at SkyandTelescope.com/skychart




Facing North
Facing NW
Facing West
Facing SW
Facing South
ECLIPTIC
EQUATOR
Zenith
AURIGA
Capella
PERSEUS
Algol
M34
TRIANGULUM
M33
ARIES
Pleiades
Hyades
Aldebaran
TAURUS
PISCES
M38
M36
M37
M35
Castor
Pollux
GEMINI
M44
M67
CANIS MINOR
Procyon
MONOCEROS
Betelgeuse
ORION
M42
Rigel
Mira
CETUS
ERIDANUS
M50
M48
Sirius
M47
M46
CANIS MAJOR
M41
M93
LEPUS
COLUMBA
CAELUM
FORNAX
AQUARIUS
PYXIS
PUPPIS
Canopus
PICTOR
DORADO
HOROLOGIUM
PHOENIX
SCULPTOR
Fomalhaut
ANTLIA
VELA
CARINA
30 Dor
RETICULUM
Achernar
Large Magellanic Cloud
VOLANS
Small Magellanic Cloud
HYDRUS
PISCIS AUSTRINUS
η Car
IC 2602
CHAMAELEON
47 Tuc
TUCANA
GRUS
MUSCA
OCTANS
CRUX
APUS
INDUS
CENTAURUS
Hadar
ω Cen
TRIANGULUM AUSTRALE
PAVO
CIRCINUS
6752
2h
5h
8h
14h
17h
20h
23h
+40°
+20°
0°
–20°
–40°
–60°
–80°
Galaxy
Double star
Variable star
Open cluster
Diffuse nebula
Globular cluster
Planetary nebula

Fred Schaaf
Tonight's Sky

Many bright beginnings

The sky offers a number of choices for marking the start of your year.

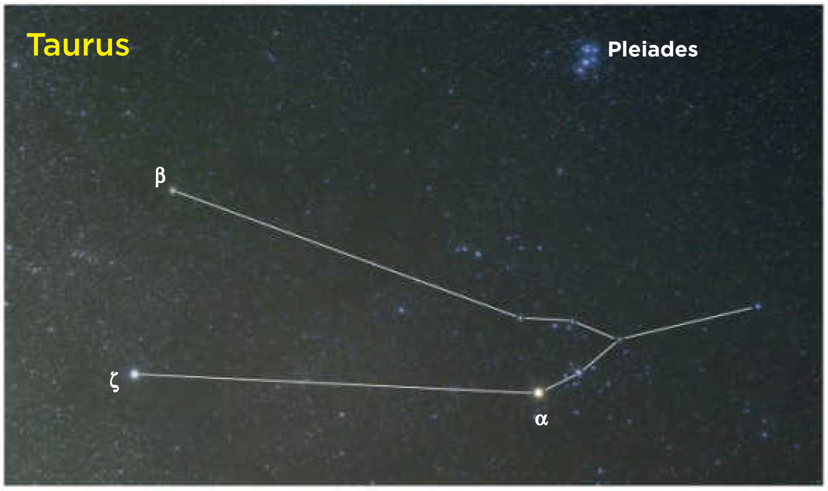
Are you ready to celebrate a happy New Year? In today's international secular calendar, the first day of the year is, of course, January 1st.

But this has been far from the case in many individual cultures and times. Let's take a look at a few of these — they're all based on astronomy and a few on the positions of very specific stellar objects. Then let's see how, during a January evening of observing, we can celebrate several different times we might regard as a fitting start of a celestial calendar or clock.

Welcome to January, the eleventh month. The ancient Roman calendar began with March. That's why September through December have the root words for seven through ten in their names: they were the seventh through tenth months of the year. (The fifth and sixth months were Quintilis and Sextilis; they were renamed to honour Julius Caesar and Augustus Caesar — and became our July and August.) In England and its American colonies, the year began with March until 1752.

So what — or who — is January named after? The ancient Roman god Janus, who literally had two faces, one looking forward and the other backward through the door. That seems wonderfully appropriate for the start of a calendar because it's a time when all of us cast a look back to the old year and forward to the new. But this persumably wasn't what the Romans intended, given that their January (Januarius) was the 11th month of the year.

A modern astronomical twist is that one of Saturn's moons, Janus, has a two-part, forward-and-backward connection not known



BOB KING

when it was named. Janus is one of two broken halves of an earlier Saturnian moon. The other 'half' is Epimetheus and, amazingly, it trades places with Janus, switching which moon leads and which one trails, as they orbit near the rings.

The Sirius-based and Pleiades-based years. Several cultures based their year on positions of nighttime stellar objects — objects that happen to be splendidly visible on January evenings. The ancient Egyptians noted that the heliacal (dawn) rising of Sirius coincided with the annual summer flooding of the Nile — so this rising became the marker of the Egyptian New Year. The Druids chose the mid-autumn acronychal (sunset) rising of the Pleiades, probably when the year's agriculture ended, to mark their New Year (a holiday that eventually transformed into Halloween).

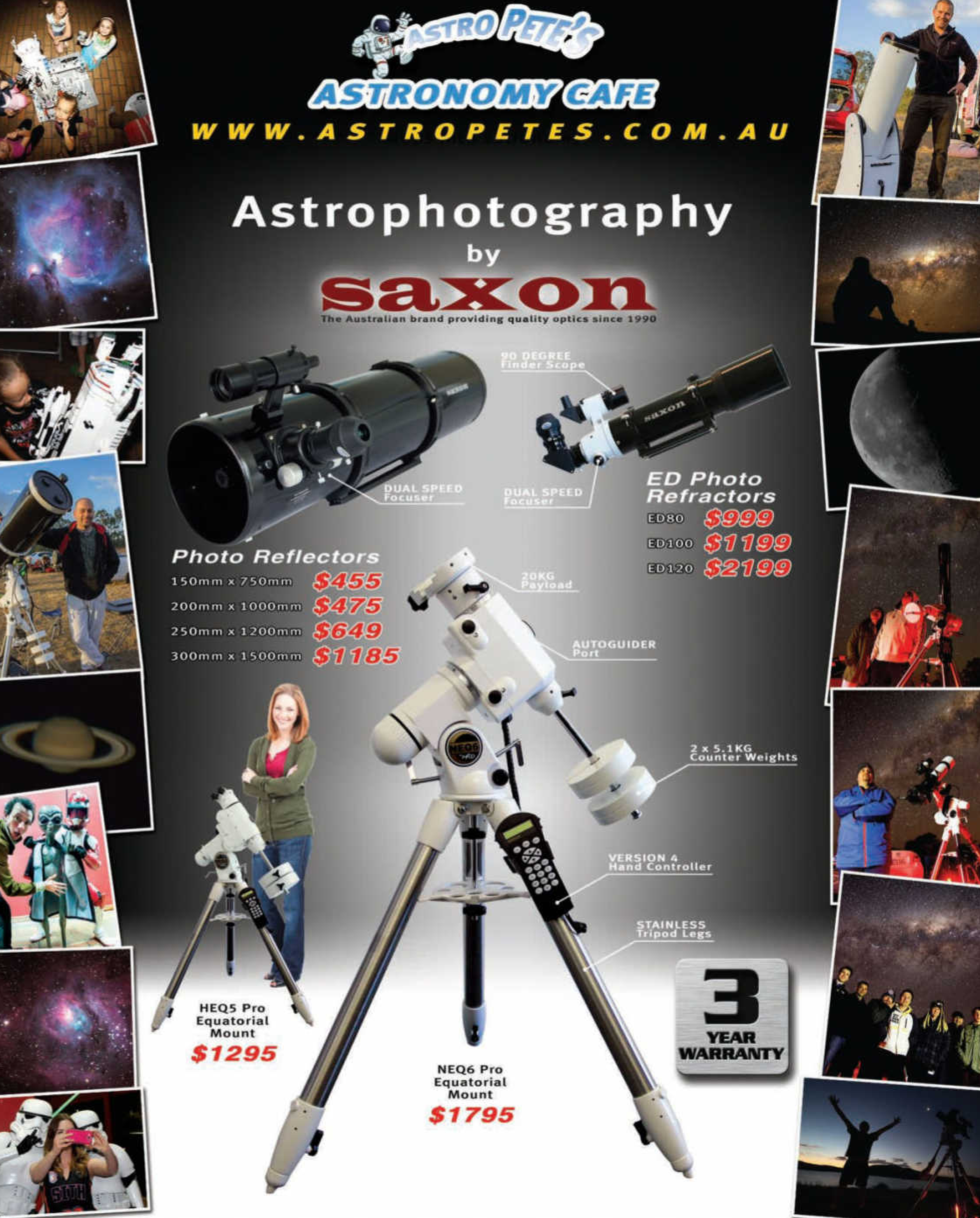
Four beginnings on a summer evening. But we could pick several sidereal times that occur on January evenings to be our own unofficial start of the starry year.

First, nightfall in early January. Which hour of right ascension is on or near the meridian? The zero hour. M31, the Andromeda Galaxy, is near due north. Orion has just risen.

But suppose we look a few hours after nightfall. Now on the meridian is noble Taurus, featuring the Hyades, Pleiades and the Crab Nebula, and Regulus has risen. And why is this an appropriate 'starting time' for the heavens? 'A' may be the first letter of our alphabet because its original upside-down form was a little picture of Taurus and his horns — and something like 4,000 years ago Taurus contained the vernal equinox and was therefore the first constellation of the zodiac.

A little longer after nightfall, Leo is fully risen, but what's on the meridian makes this another candidate for being our starting-time-of-the-stars hour: Orion, perhaps the most magnificent of the constellations.

We finally reach midnight — and what's on the meridian? Marvelously, the brightest star by far, mighty Sirius — making this another grand stellar beginning. ✦



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A New Year's sky show

Venus and Saturn come together for a close conjunction early in January.

JONATHAN NALLY

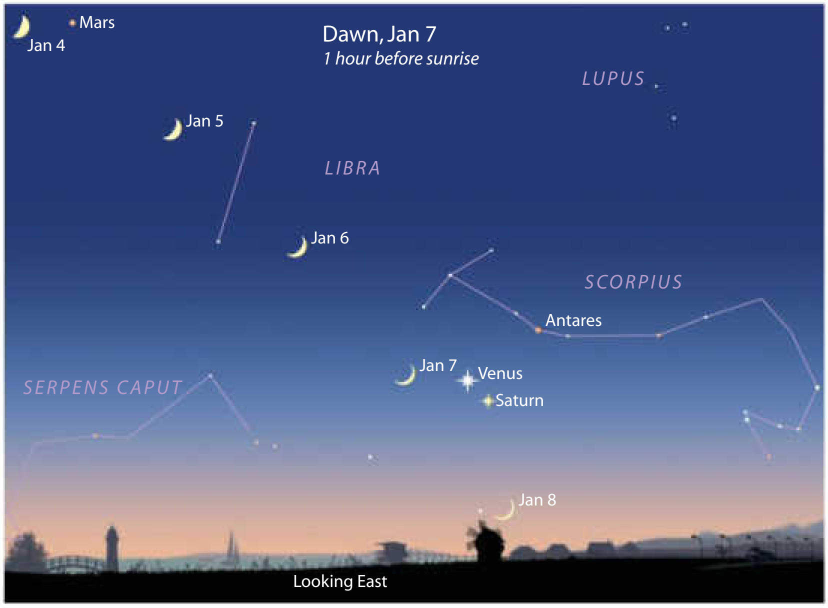
Warm summer nights are ideal for stargazing, no matter whether it's just catching a glimpse here and there as we go about our other daily activities, or during dedicated observing sessions under our clear, southern skies.

The innermost planet, Mercury, will be very low on the western horizon at the start of January, soon disappearing into the Sun's glare before returning to our pre-dawn skies in the east at the end of the month.

Venus will be a stunning sight out to the east in the pre-dawn sky until the end of April. Shining brightly at around magnitude –4.0, the cloud-covered planet cannot be missed. Watch for the Moon, Saturn and Scorpius' brightest star, Antares, nearby on the 7th. Saturn will move a bit closer over the following two nights, coming to just half a degree away from Venus on the 9th. If you have a telescope, train it on Venus and you'll see that it shows a phase (ie. not a fully illuminated disk), just as the Moon does.

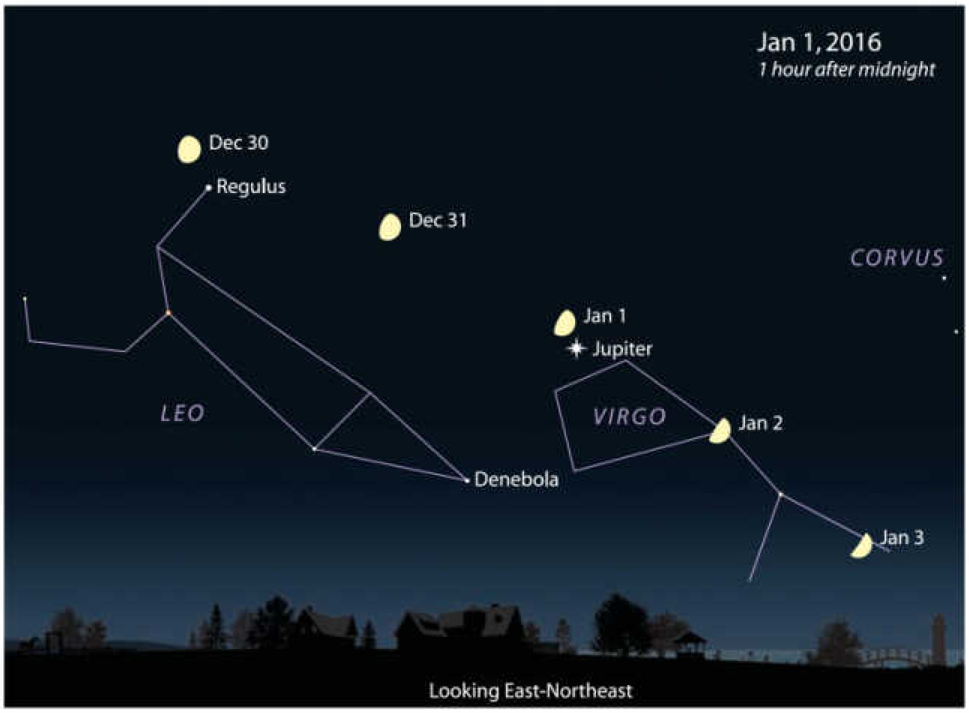
Mars will rise just before 1:00am at the beginning of the month, and by just before midnight by the end of January. The planet will be at magnitude 1.1 and only 6.1 arcseconds in diameter. Watch for the Moon nearby on January 4. Around the start of the month, Mars will be within a couple of degrees of the star Spica (Alpha Virginis), but by month's end will have moved close to Zubenelgenubi (Alpha Librae). In May, the Red Planet will reach opposition, and will have brightened to magnitude –2.0 and will appear much larger, around 18.5 arcseconds.

The Solar System's largest planet, Jupiter, will be well placed for viewing in the late evening during January, rising just after 11:00pm at month's start and just after 9:00pm by month's end. In fact, it will combine with the Moon very close nearby on the night of December 31 to help usher in the New Year (see diagram). During January, Jupiter will shine at a very respectable magnitude –2.3 and will be a whopping 40.7 arcseconds across. Grab your binoculars and see how many of its Galilean moons you can see. Can you see all four? Watch them



The pre-dawn sky in early January will be graced by Venus and Saturn, with Antares and the crescent Moon nearby.

Jupiter and the Moon will appear close together on the last night of the year. Wait another hour, and Mars will have risen over the eastern horizon too.



change position night after night.

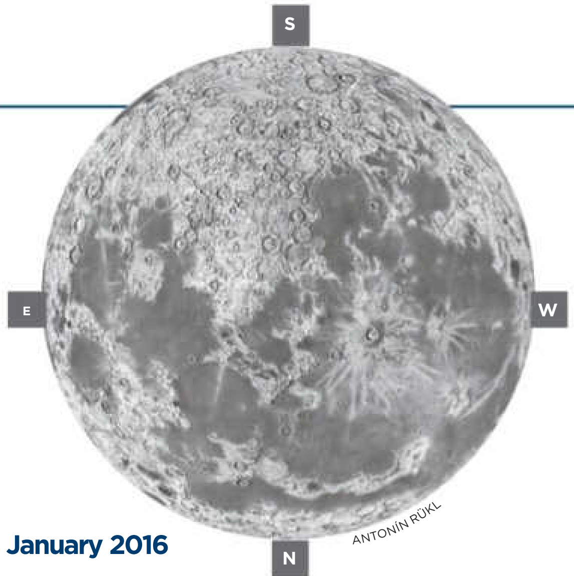
As mentioned, the ringed planet, Saturn, will be close to Venus in the pre-dawn sky during January, coming very close on 7th to the 9th. Shining at magnitude 0.5, it will be a fine sight to the naked eye, but even more impressive through a telescope (even just a small one). The planet's rings are nicely tilted towards us at the moment.

Finally, an annual milestone for our own planet — Earth will reach perihelion (its closest point to the Sun) on January 3, at a distance of 147,100,185 kilometres. ✦

January Events Of Note

1	Jupiter 1.5° north of the Moon
2	Comet Catalina 0.7° NW of Arcturus
3	Earth at Perihelion
3	Spica 5° south of the Moon
4	Mars 1.5° south of the Moon
5	Mercury stationary
7	Venus 6° north of Antares
7	Antares 10° south of the Moon
7	Venus 3° south of the Moon
7	Saturn 3° south of the Moon
9	Jupiter stationary
9	(noon) Saturn 0.09° south of Venus
16	Vesta 5° south of the Moon
16	Uranus 1.5° north of the Moon
20	Aldebaran 0.5° south of the Moon
25	Venus 0.6° north of the Trifid Nebula
25	Venus 0.2° north-west of M21
26	Regulus 3° north of the Moon
26	Mercury stationary
28	Jupiter 1.4° north of the Moon
30	Spica 5° south of the Moon
30	Venus 1.0° of NGC 6642

Times are listed in Australian Eastern Standard Time



January 2016

Phases

Last Quarter	January 2, 03:30 UT
New Moon	January 10, 01:31 UT
First Quarter	January 16, 23:26 UT
Full Moon	January 24, 01:46 UT

Distances

Apogee	January 2, 12h UT	404,277 km
Perigee	January 15, 02h UT	369,619 km
Apogee	January 30, 09h UT	404,553 km

Far southern meteor shower

Keep your eyes peeled for an Alpha Centaurids outburst

CON STOITSIS

Meteor shower observers could be in for a real treat in late January and early February. The Alpha Centaurids, a minor shower mainly suitable for Southern Hemisphere observers, is known for producing very bright meteors, but rates in most years are very low — approximately 6 per hour at the time of maximum. Yet in some years, 1974 and 1980 for example, rates as high as 30 per hour were recorded.

The Alpha Centaurids are active from January 28 to February 21. Based on the idea that the shower has a long orbital period, the IMO (International Meteor Organisation) has advised that there is a possibility of a fresh outburst on February 8, and rates could reach as high as 25 per hour!

From the Southern Hemisphere, the radiant (the localised region in the sky from the meteors seem to originate) is almost circumpolar at this time, and is very well placed from late evening. Coincidentally, the new moon will occur on the 8th, make conditions close to perfect for observation. If you want to try and spot some of the meteors, you should commence observing from 11pm on that evening.

Alpha Centaurids enter the atmosphere at 56 km per second, which makes them of medium speed, and often leave persistent trains, some lasting for over ten minutes. Their average magnitude is 1.8. Colours are mixed, but yellow is typical. In recent years, reports of fireball and bolide activity have become common.

The IMO (imo.net) is very keen to receive observation reports of this meteor shower, as in previous years it has been almost entirely ignored by observers in the Northern Hemisphere, from where the radiant is low or doesn't rise at all. In the Southern Hemisphere the situation surprisingly is the same, even though the radiant is perfectly placed for observation. ✦

Alpha Centaurid meteor rates are forecast to reach as high as 25 per hour on the night of February 8/9. This is the view looking south at midnight on February 8.

Con Stoitsis is the director of the Astronomical Society of Victoria's comet and meteor sections.

Last chance to see Catalina

One of 2015's better comets finally heads north and out of our skies

DAVID SEARGENT

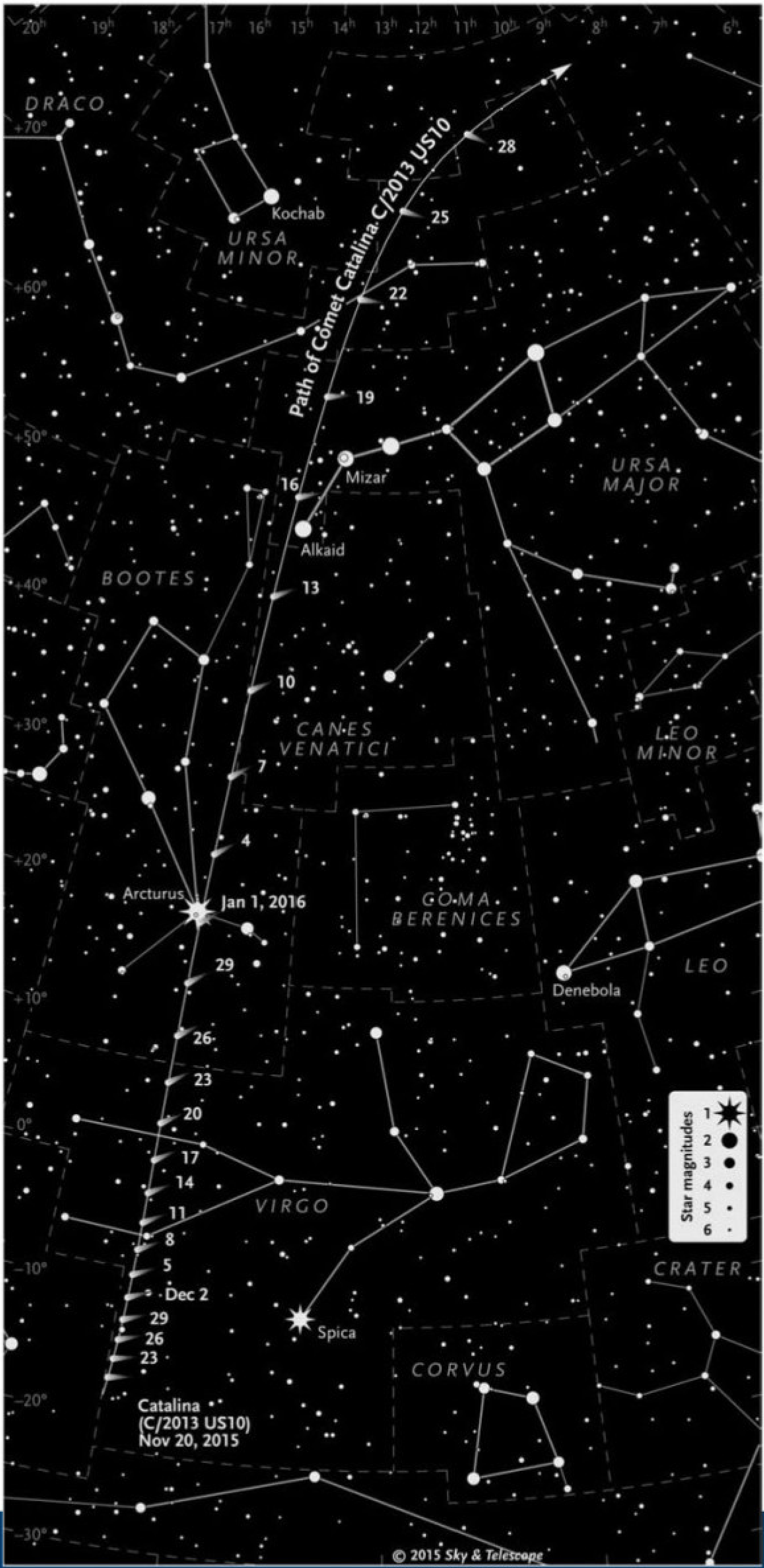
Early January provides the last chance for observers at mid-southern latitudes to see C/2013 US10 (Catalina) as it sinks below the northern horizon on its way out from the Sun.

This comet was a nice binocular object during the early spring of last year as it cruised the southern circumpolar skies while sporting a short, tapering dust tail. Passing perihelion at 0.82 a.u. on November 15, the comet remained too close to the Sun in the skies until December when it emerged low in the morning twilight.

Continuing its northward trek, Catalina begins the New Year in Bootes, close to the bright star Arcturus, very low in the north-east before dawn from mid-southern latitudes. By the middle of January however, it will be far north, passing quite close to the star Eta Ursa Majoris; a well-placed object for our Northern Hemisphere colleagues but, alas, no longer for us.

The comet's brightness is difficult to forecast following perihelion. Nevertheless, it did become at least one magnitude brighter than predicted during September, and if this trend continues it could be around magnitude 5.5 to 6.0 as 2016 begins. This is probably being too optimistic, however it should still be quite easy to observe at low altitude, given a clear horizon and a good pair of binoculars. ✦

David Seargent's latest book on comets, Snowballs in the Furnace, *is available from Amazon.com*



Comet C/2013 US10 (Catalina) is rapidly heading north, and will soon be out of sight for observers in the Southern Hemisphere.

The shoulder of the Bull

A visit to some double stars near the Pleiades in Taurus

ROSS GOULD

This month we pay another visit to the western part of Taurus. The objects I've chosen have STF (•) numbers, for F.G.W. (Wilhelm) Struve, or STT (• •) for his son Otto Struve. Wilhelm's survey of the 1820s and 1830s, checking stars brighter than 9th magnitude to declination -15°, resulted in a catalogue of 3,110 double stars. Otto later added more than 500.

We'll begin some 5 degrees NW of the Pleiades, where two contrasting doubles are in the same field, only 10′ apart. The brighter pair is **STF 401** (• •• ••), hardly changed since Wilhelm Struve's 1830 measure, the near-equal bright white stars being 11.4″ apart. **STFA 7** is NNW from it, a much wider double of 7th-magnitude yellowish stars 44″ apart, again not showing change. In each pair the stars have common proper motions (cpm), so they're probably binaries with huge, slow orbits. It's an attractive combination, and even 60mm aperture shows them well.

From STF 401, 2.5-degrees NE is **STF 427**, first measured in 1824, and again a cpm pair showing no real change. The pale yellow 7th-magnitude stars are an easy 7″ apart, well seen even through small telescopes in a field with several other middling-bright stars.

Eastwards 3 degrees from STF 401 is the pair STTA 38, an Otto Struve double that's merely an optical alignment of bright stars 135″ apart. It was an easy little pair through an 8×50 finder. At low power with my 140-mm refractor, there was an irregular line of lesser stars at right angles to the pair. Both stars are yellowish; Sissy Haas in her book *Double stars for Small Telescopes* describes the colours more poetically: *whitish gold*, as seen through a 60-mm refractor. Pairs like this are best seen at very low power.

Voyaging now a long way south, **STF 422** is 10′ north of the 4th-magnitude star 10 Tauri. STF 422 is a very-long-period binary for which a preliminary orbit has been calculated, around 2,000 years. Over time, both angle and separation have shown some increase. The primary is slightly variable. It's an attractive pair: the primary orange-yellow (T.W. Webb: *"gold"*), the secondary bluish-white. Despite nearly three magnitudes of brightness difference, it's not difficult at 7″ separation, and 10 cm should show it well.

Northward 10 degrees and a little east is **30 Tauri, STF 452**, known since William Herschel's time but with a first measure by Wilhelm Struve in 1830. Ernst Hartung, in his classic book *Astronomical Objects for Southern Observers*, describes it as a *beautiful and easy pair, pale yellow and reddish grey*. With my 23.5cm SCT at 98×, I saw a bright pale-yellow star with a tiny companion easily seen, a nice brightness contrast effect. Of some interest are the colour descriptions by the 19th century observers, W.H. Smyth and T.W. Webb, using achromat refractors — Smyth calls the primary star *"pale emerald,"* and Webb *"bluish green"*.

Moving northwards again we find near the Pleiades, **STT 64**, only 20′ SE of the naked-eye pair at the trailing end of the cluster (27 and 28 Tauri). STT 64 has a bright, white primary star, with two lesser companions in a straight line running southwest, both 10th magnitude. With my 140-mm refractor at 67× the wider companion was seen; 160× showed the closer companion as well. This nearer companion might be compared for seeing difficulty with the AE pairing in the Orion Nebula's Trapezium. This is a bit closer than Orion's, but with less brightness difference.

Our last double is about 1.5 degrees NNE from the Pleiades. **STT 65** is a binary of 61 years orbital period, discovered in 1846. Hartung had noted that *"The plane of the orbit of this close pale yellow binary is nearly in the line of sight; the stars will be widest in 1969, and in 1962 they were resolved by 25cm"*. After that it gradually closed. In recent times the stars have been too close for amateur telescopes, as the separation from 1992 to 2011 was below 0.3″.

However STT 65 is now widening, with a 2016 separation of 0.45″. Despite some brightness difference (0.8 mag), elongation with 20 cm aperture and a Rayleigh Criterion split with 30 cm should be possible. Hipparcos data places STT 65 at 184 light-years away, at which distance 0.7″corresponds to 40 a.u. in projection, larger than the orbit of Neptune. ✦

***Ross Gould** has been a long-time observer from the suburban skies of Canberra. He can be reached at rgould1792@optusnet.com*

More doubles in western Taurus

Star Name	R. A.	Dec.	Magnitudes	Separation	Position Angle	Date of Measure	Spectrum
STFA 7	03^h 31.1^m	+27° 44′	7.4, 7.8	44.0″	234	2014	B9
STF 401	03^h 31.3^m	+27° 34′	6.6, 6.9	11.4″	269	2014	A2V
STF 422	03^h 36.8^m	+0° 35′	6.0, 8.9	7.1″	274	2013	G8V, K6
STF 427	03^h 40.6^m	+28° 46′	7.4, 7.8	7.0″	208	2007	A1V, A2V
STTA 38	03^h 44.6^m	+27° 54′	6.8, 6.9	135″	038	2013	F4V,
30 Tau (STF 452)	03^h 48.3^m	+11° 09′	5.1, 9.8	9.6″	058	2012	B3V, F5V
STT 64	03^h 50.0^m	+23° 51′	AB 6.8, 10.2	3.2″	236	2012	B9.5V
″	″	″	AC 6.8, 10.5	10.3″	235	2012	
STT 65	03^h 50.3^m	+25° 35′	5.7, 6.5	0.45″e	201e	2016e*	A2V, A5V

Data from the *Washington Double Star Catalog*. *ephemeris numbers, for a widening binary

Y Hya is located at 09h 51m 03.72s, -23° 01' 02.4" (epoch J2000). This chart (courtesy of the AAVSO) is approximately 5 degrees east to west, and visual magnitudes are shown without decimal points to avoid confusing them with very faint stars — so 75 denotes a 7.5-magnitude star.

Heading into Hydra

Y Hydrae has been monitored for more than a century.

ALAN PLUMMER

Recently we've covered the observation of some bright carbon stars and discussed what they are — a kind of long-period variable that is in a short-lived evolutionary stage (cosmically speaking), with changes that can become apparent over years or decades.

And here's one more, Y Hydrae. It's bright enough to have been catalogued in 19th century sky surveys, but its identity as a variable wasn't discovered until 1896, by Louisa Wells and Emily Boyce of the Harvard College Observatory team. The American Association of Variable Star Observers (AAVSO) database shows that it has been regularly observed since 1903.

Y Hya ranges between magnitudes 6.2 and 7.4 over a period of 154 days. This year, its maximum light is expected to occur roughly around January 16.

The chart shows its position — you'll need a star atlas to locate the field. Take a look once per fortnight with binoculars or a small telescope, and if you feel like it, join the many observers contributing to the science of variable stars by getting in touch with the AAVSO (aavso.org). ✦

Alan Plummer *observes from the Blue Mountains west of Sydney, and can be contacted on alan.plummer@variablestarssouth.org*

JUPITER IN JANUARY

Jupiter in January grows from 39 to 42 arcseconds wide. Any telescope will show its four big Galilean moons. Binoculars almost always show at least two or three.

Below are the times, in Universal Time, when Jupiter's Great Red Spot should rotate across the planet's central meridian. The dates, also in UT, are in bold.

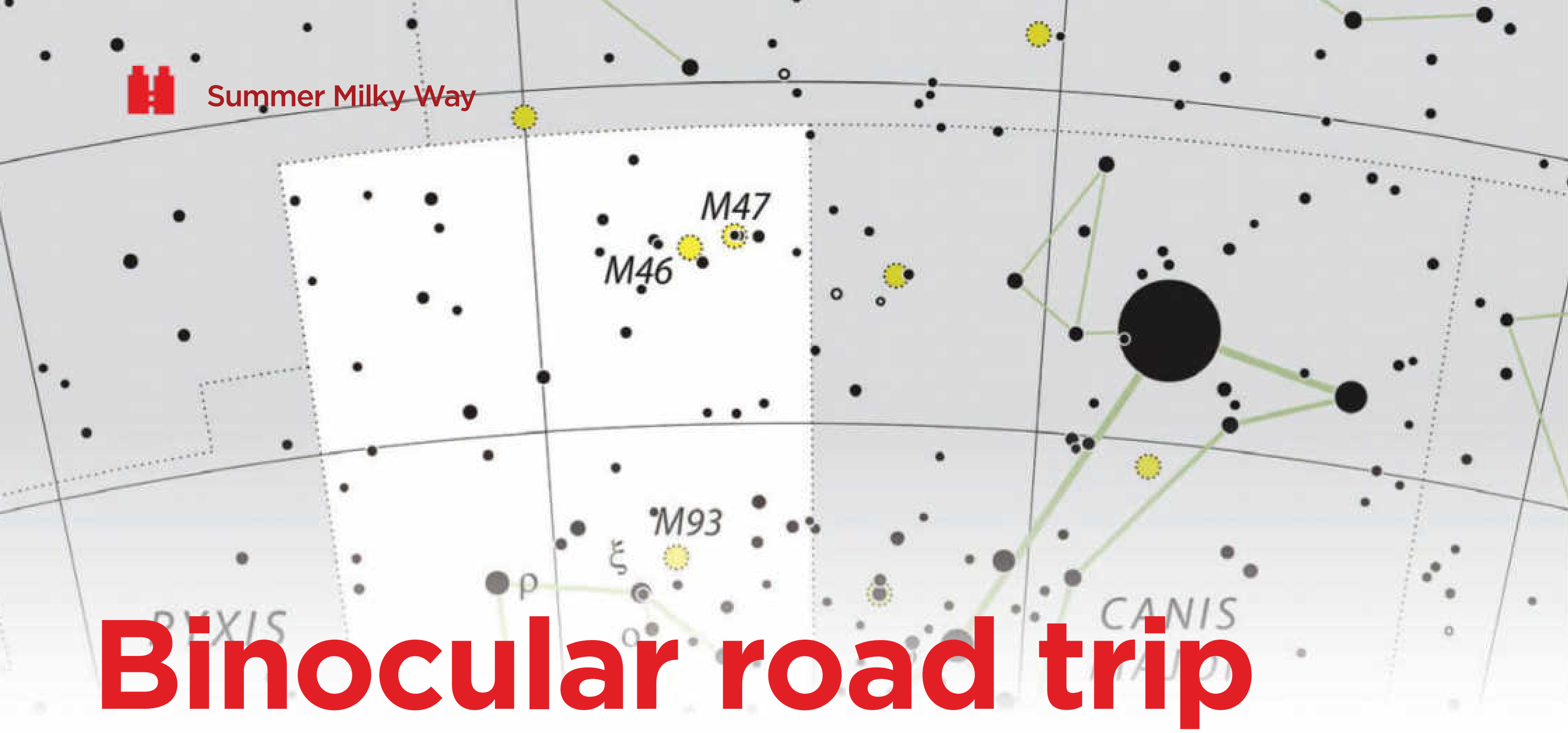
December 16, 0:47, 10:42, 20:38; 17, 6:34, 16:29; 18, 2:25, 12:21, 22:16; 19, 8:12, 18:08; 20, 4:03, 13:59, 23:55; 21, 9:50, 19:46; 22, 5:42, 15:37; 23, 1:33, 11:29, 21:24; 24, 7:20, 17:16; 25, 3:11, 13:07, 23:03; 26, 8:58, 18:54; 27, 4:49, 14:45; 28, 0:41, 10:36, 20:32; 29, 6:28, 16:23; 30, 2:19, 12:15, 22:10; 31, 8:06, 18:02.

January 1, 3:57, 13:53, 23:48; 2, 9:44, 19:40; 3, 5:35, 15:31; 4, 1:27, 11:22, 21:18; 5, 7:14, 17:09; 6, 3:05, 13:00, 22:56; 7, 8:52, 18:47; 8, 4:43, 14:39; 9, 0:34, 10:30, 20:25; 10, 6:21, 16:17; 11, 2:12, 12:08, 22:04; 12, 7:59, 17:55; 13, 3:50, 13:46, 23:42; 14, 9:37, 19:33; 15, 5:29, 15:24; 16, 1:20, 11:15, 21:11; 17, 7:07, 17:02; 18, 2:58, 12:53, 22:49; 19, 8:45, 18:40; 20, 4:36, 14:31; 21, 0:27, 10:23, 20:18; 22, 6:14, 16:09; 23, 2:05, 12:01, 21:56; 24, 7:52, 17:47; 25, 3:43, 13:39, 23:34; 26, 9:30, 19:25; 27, 5:21, 15:17; 28, 1:12, 11:08, 21:03; 29, 6:59, 16:55; 30, 2:50, 12:46, 22:41; 31, 8:37, 18:33.

These times assume that the spot will be centred at System II longitude 230°. It will transit 1 2/3 minutes earlier for each degree less than 230°, and 1 2/3 minutes later for each degree greater than 230°. Features on Jupiter appear closer to the planet's central meridian than to the limb for 50 minutes before and after they transit.

ESO/F. CHAR

Southern star trails rise over telescope domes at the La Silla observatory in Chile.



Binocular road trip

Take a guided tour of some of the Milky Way's top attractions

MATHEW WEDEL

In the clear summer skies, the Milky Way seems to bend slightly closer to the Earth, inviting us to a deeper appreciation of its glittering starfields. It's at this time of the year that I'm more likely to reach for binoculars than a telescope. I love the bright spectacles in Orion, Taurus and Gemini, but there's a lot more to see in the Milky Way. This binocular tour will take you down the spine of Canis Major (the Big Dog), across Puppis (the Poop Deck), and north again to the boundary that keeps Hydra (the Water Snake) away from Monoceros (the Unicorn).

I made these observations using 15×70 binoculars with a 4.4° field of view. Most of the objects we'll visit on this tour are also visible through smaller instruments, especially if they're mounted on a tripod or braced against something sturdy. Equally important for rewarding binocular observing is good dark adaptation. If I block out any incidental light, I'm able to go deeper and see more, even from suburban skies.

Sirius makes a good starting point for our tour. From Sirius, move directly south about four degrees to find **M41**, a bright open star cluster. Before you move on, notice how the brighter stars in the cluster form a pair of concentric curls like breaking waves.

Another 4° slide to the east-southeast will bring you to **Collinder 121** (Cr 121), a loose association dominated by Omicron^1 (o^1) Canis Majoris. Evidence is mounting that the brighter O and B stars in this field are separate from the open cluster, which lies about 3,500 light-years away. Omicron^1 itself is also fairly distant, at nearly 2,000 light-years, but as an orange, *K*-type supergiant it's incredibly luminous. The complexity of the view here is a useful reminder that space has depth — we don't look *at* the night sky so much as *into* it.

Our gentle arc to the east continues with a third 4° hop, southeast from Omicron^1 to the much brighter Delta (δ) Canis Majoris, also known as Wezen. This is another big, young supergiant, and we'll use it as a base camp for a little side trip. Start by taking in the arc of bright stars east of Delta, which forms a miniature 'corona' asterism about 2° across. The brightest star in the arc is Omega (ω) Canis Majoris. Omega is a variable star, normally a modest magnitude 4.1 but occasionally brightening up to 3.6. The change in brightness is caused not by the star itself, apparently, but by the formation, outburst and dissipation of a circumstellar disk.

About 2° north-northeast of Omega is a pair of bright stars orientated north-to-south: 29 Canis Majoris to the

The loose open cluster Collinder 121 is an easy target for binocular observers. Look for Omicron1 Canis Majoris, an orange supergiant (spectral type K2.5Iab) that fronts the open cluster.

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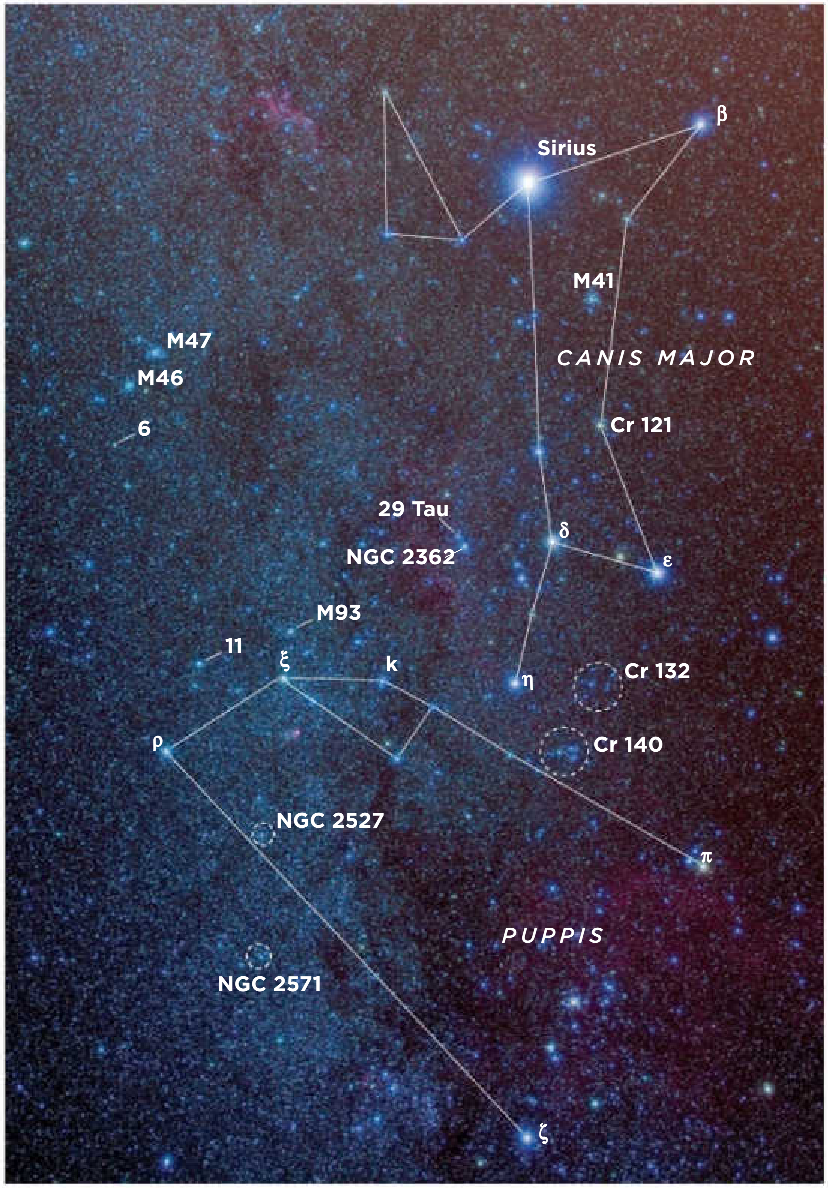


ALAN DYER

north and Tau (τ) Canis Majoris to the south. Take a close look at Tau. If you're under good skies, you may catch a glimpse of the open cluster **NGC 2362** as a faint wisp of light surrounding the brighter star. Or rather, brighter stars: Tau is actually a stellar system of four giant stars in a tight gravitational bear hug, plus a single smaller star, probably captured, that lies 13,000 a.u. from the rest.

Another beautiful double awaits you just over 1° north-northwest of the 29–Tau pair. This is **Herschel 3945** (h3945). Some observers report splitting the beautiful blue and gold components with 10×50 binoculars, but I have to go up to the 15×70s, braced very securely, to get a clean split. Give it a shot and see what works for you.

Now go back to bright Delta and shoot through the 'corona' asterism like an arrow out of a bow. About 5° to the southeast you'll encounter **Eta (η) Canis Majoris**, also known as Aludra, a wide unequal double. South of Eta are two more Collinder clusters: big, diffuse **Cr 132** to the southwest and the more compact **Cr 140** due south. If you park Aludra on the north edge of your field you should be able to pick up both clusters in the same view, even in the limited field of 15×70 binos.

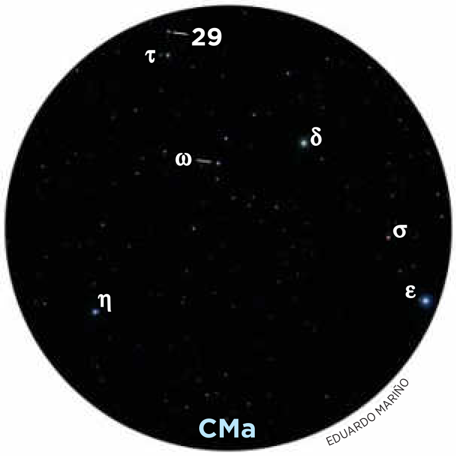
Roughly 4° northeast of Aludra is the double star k Puppis. At only 9.9 arcseconds apart, the two components would be a tough split for instruments with a magnification lower than 30×. Rather than trying for a probably-impossible split, relax and take in the very rich field surrounding k Puppis, which rivals some of the better Collinder clusters. Another three degrees along the same line from Aludra to k Puppis will bring you to **Xi (ξ) Puppis**. With its wide, bright companion, Xi is a fine binocular double. The primary looks softly yellow to me, and the companion blue-white. Now follow a chain of faint stars northwest about 1.5° to find a tight group of faint stars, **M93**. If M93 seems dim, it's because it is so far away: at 3,600 light-years it's one of the more distant open clusters in the Messier catalogue.

For a charming view closer to home, sweep three degrees east of Xi to find Rho (ρ) Puppis. About 2° north of the line between Xi and Rho, you'll find 11 Puppis, which makes a wide triangle with the two other stars. Much like the field around k Pup, the vicinity of 11 Pup is packed with blue-white gems. And by a quirk of cosmic architecture, the fields around k and 11 mirror each other on opposite sides of Xi — double rich fields around a double star.

Drop down 4° south from Rho to find the open cluster **NGC 2527**. Another 3° to the east-southeast lies another open cluster, **NGC 2571**. The two clusters lie close enough to hold in the same binocular field and they make an instructive contrast. Through my 15×70s, NGC 2571 is a faint patch of light that just starts to resolve with patient study. I find the individual stars in NGC 2527 easier to resolve, even though the cluster itself seems a bit dimmer overall. This isn't surprising in view of the clusters' distances. NGC 2571 is truly remote as open clusters go, at about 4,000 light-years away; NGC 2527 is only half as far off.

The wide triangle formed by Xi, Rho and 11 Puppis is an arrowhead pointing north and a bit west. Follow the arrow about five degrees and you'll find a line of three equally bright stars trending to the northwest — 16 Puppis, HD 65810 and 6 Puppis. Just over 1° north of 6 Pup is the fine binocular double **Knott 4**. With a separation of 129″ it should be an easy split. Two degrees northwest of Knott 4 you'll find the famous pair of Messier open clusters, **M46** and **M47**.

If appreciating celestial objects through a telescope is enhanced by knowing what they are, enjoying them through binoculars is about seeing them in context — and nowhere is that more true than with M46 and M47.



First catalogued in the mid-17th century by Giovanni Batista Hodierna, open cluster M41 is visible to the naked eye from dark skies. With 15×45 image-stabilised binoculars, you should be able to resolve some 30 stars.

Use Delta Canis Majoris as a waymarker on the path to Omega, Tau and 29 CMa. Eta lies approximately 5° to the southeast of your waymark.

First, compare the clusters themselves. M47 is a bright shotgun blast of splashy stars, compared to the dense swarm of dimmer lights that makes up M46. Now, widen your view. Notice how the pair is bounded to the east and west by wide, canted pairs of stars. These are 2 and 4 Puppis on the east, and KQ Puppis and HD 60325 on the west. Another bright star, HD 61722, sits between the clusters to the south, much closer to M46 than to its sibling. Taken together, the five bright stars on the east, west and south of the clusters form a wide 'bowl' that seems to hold the clusters and associations stacked within.

Milky Way travel itinerary

Object	Type	Spec	Mag(v)	Size/Sep	RA	Dec.
Messier 41	Open cluster	—	4.5	38′	06^h 46.0^m	–20° 45′
Collinder 121	Open cluster	—	2.6	50′	06^h 54.2^m	–24° 43′
NGC 2362	Open cluster	—	4.1	8′	07^h 18.7^m	–24° 57′
Herschel 3945	Double star	*K3I, dF0*	5.0, 5.8	26.8″	07^h 16.6^m	–23° 19′
Eta Canis Majoris	Double star	*B5I*	2.4, 6.8	179″	07^h 24.1^m	–29° 18′
Collinder 132	Open cluster	—	3.6	95′	07^h 14.4^m	–31° 10′
Collinder 140	Open cluster	—	3.5	42′	07^h 23.9^m	–32° 12′
Xi Puppis	Double star	*G6Ib*	3.4, 13.0	4.8″	07^h 49.3^m	–24° 51′
Messier 93	Open cluster	—	6.2	22′	07^h 44.5^m	–23° 51′
NGC 2527	Open cluster	—	6.5	22′	08^h 05.0^m	–28° 09′
NGC 2571	Open cluster	—	7.0	13′	08^h 18.9^m	–29° 45′
Knott 4	Double star	*M2II, M2III*	6.5, 6.6	129.4″	07^h 47.8^m	–16° 01′
Messier 46	Open cluster	—	6.1	27′	07^h 41.8^m	–14° 49′
Messier 47	Open cluster	—	4.4	30′	07^h 36.6^m	–14° 29′
NGC 2423	Open cluster	—	6.7	19′	07^h 37.1^m	–13° 52′
NGC 2539	Open cluster	—	6.5	22′	08^h 10.6^m	–12° 49′
Messier 48	Open cluster	—	5.8	54′	08^h 13.8^m	–05° 45′

Angular sizes and separations are from recent catalogues. Visually, an object's size is often smaller than the catalogueed value and varies according to the aperture and magnification of the viewing instrument. Right ascension and declination are for equinox 2000.0.

At 3,600 light-years, M93 is one of the more distant open clusters in the Messier catalogue. Look for the bright giant stars HD 62679 and TYC 6540-4176-1 to the southeast of the cluster's centre.

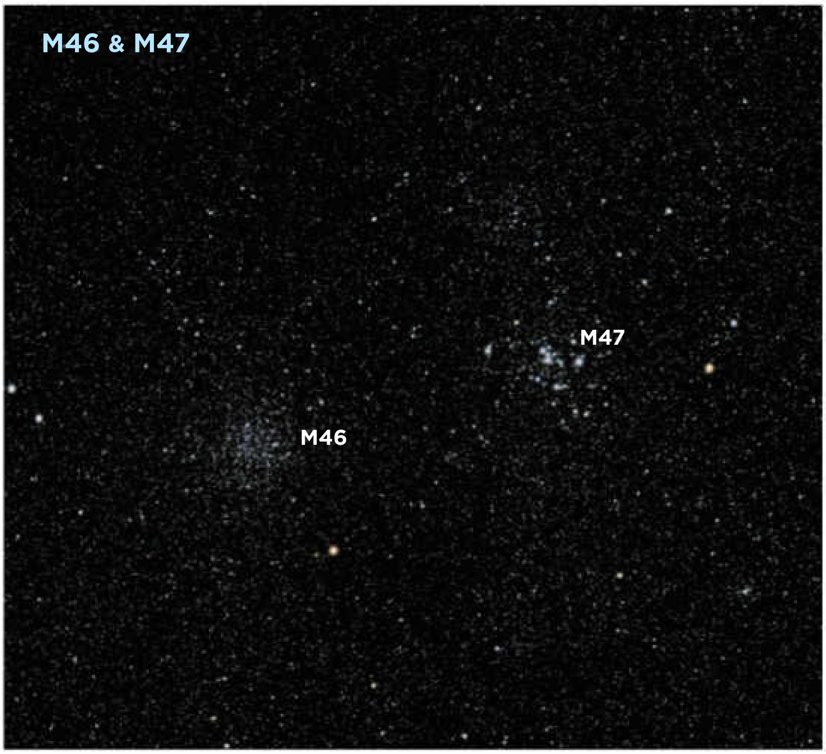
Although typically considered a telescopic object, NGC 2571 can be picked up with 15×70 binoculars; look for the roughly linear distribution of the cluster's brighter stars.

Wait — stacked? Yes! About ½° north of M46 is a bright association that may outshine the neighbouring Messier cluster. About the same distance north of M47 is a genuine cluster, **NGC 2423**. Taken altogether, there's a lot more going on in the northwest corner of Puppis than just the two Messier objects.

For our last two stops we're going to take a couple of long strides east and north to pick up two more binocular clusters. First, line up M46 with the bright stars to the east — 2 and 4 Pup, and 9 Pup another 1.5° out. They don't fall perfectly in line, but if you sweep east-northeast from M46 about 7° along that rough line, you'll come to 19 Puppis and the open cluster **NGC 2539**. The star is only 185 light-years away, compared to 4,000 light-years for the cluster. I find NGC 2539 a challenging target. It's almost overwhelmed by the glare from 19 Puppis — if a 4th-magnitude star can be said to have glare! But spend some time here and see how many stars you can fish out of NGC 2539 by steadying your instrument and using averted vision.

That's the end of our tour of Puppis, but there's one more stop, across the border in Hydra. Another 7° sweep, this time to the north of 19 Puppis, will bring you to **M48**. This sprawling expanse of distant suns looks like a wide chevron to me. Two to three degrees north on either side are the bright stars C Hydrae and Zeta (ζ) Monocerotis. Fix these as landmarks and see if you can spot M48 with your naked eyes. I've never managed it myself, but other observers have. And when failure means that you spend a couple of minutes looking at a pretty part of the sky, there's not much to lose by trying.

There's a lot more to see in this part of the sky — the Milky Way from Puppis to Gemini and beyond is packed with wonders. Many of them are associations and asterisms that don't appear in the famous observing catalogues or 'best of' lists, but they're well worth seeking out. Realising how much there is to see beyond the Messiers was a big step in my binocular observing. I hope you get swept up in the same exploratory spirit. ✦



Visible to the naked eye under dark skies, M47 sparks to life even through modest binoculars. Under high power, the cluster's central stars jump from sparks to blazes. Neighbouring M46 appears dimmer, a cluster of pinpricks of light piercing a patch of haze.

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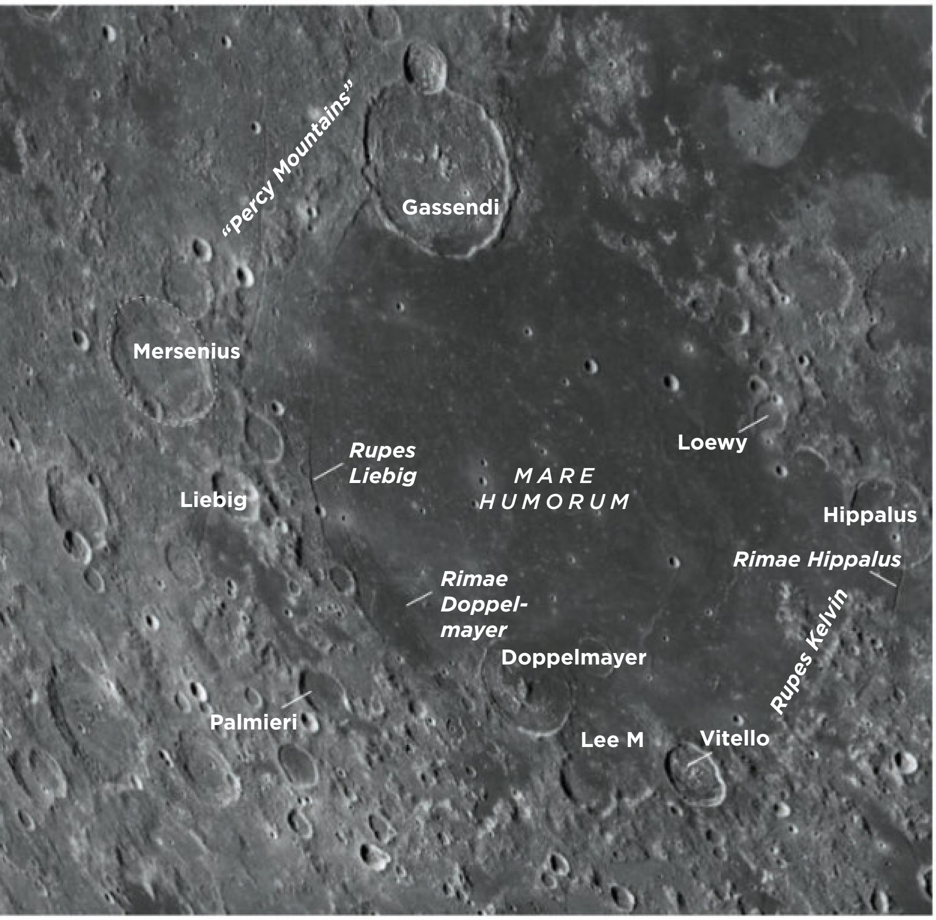
Humorum through the eyepiece

A lunar basin packed with geologic features visible through your telescope.

The dark maria are the most conspicuous features of the Moon, but more important are the giant basins that contain them. Each basin controls the geology of the area around it. One easy-to-see example is the Humorum basin, whose central depression is partially filled by the lava plains of Mare Humorum. This mid-size impact basin preserves many structural features that one can appreciate only by careful observation. So let's do so!

Younger, less-modified lunar basins (Orientale comes to mind) are defined by multiple concentric mountain ranges. We assume that the Humorum basin had them as well when it formed, but only a few fragments of the original rims survive. Can you see any? The basin's best-seen rim segment appears as a short lumpy ridge (once known as the Percy Mountains) that starts on the west side of the big crater Gassendi, which intrudes into Mare Humorum's northern boundary.



NASA / LUNAR RECONNAISSANCE ORBITER

Mare Humorum's lava flows fill a medium-size lunar basin that's 425 km across. Little remains today of the multiple rings that once marked its rim.

If you draw an imaginary circle through this range, and then continue along other isolated mountains east of the craters Mersenius and Liebig, you will find that the extrapolated circle passes along the straight Rupes Kelvin scarp on the southwestern side of the mare. To the northeast from there, the basin rim becomes harder to trace, having more gaps than continuity. This circular rim, so discontinuous that its definition depends on faith as much as evidence, has a diameter of about 425 km.

A second basin ring, even easier to overlook, is marked by a low mountain ridge parallel to the Percy Mountains but about 150 km to their northwest. Individual local hills hint at this barely visible ring curving around the western side of Mersenius, but then farther south and east it mostly disappears. The moat between the Percy Mountains rim and this larger ring is at lower elevation than most of the terrain beyond, a fact made noticeable by the occurrence of mare patches between Liebig and Palmieri, and between Ramsden and Campanus. This is a small-scale version of the low spots of Sinus Aestuum, Mare Vaporum and Mare Frigoris that occur beyond the Apennine rim of the Imbrium basin.

Looking around the shore of Mare Humorum, you'll see that the basin floor has subsided toward the basin centre. The evidence? Note the large craters with rims breached on their mare-facing sides. Examples are Doppelmayer and its larger neighbour, Lee M, along the southern extent of the mare, and Hippalus and

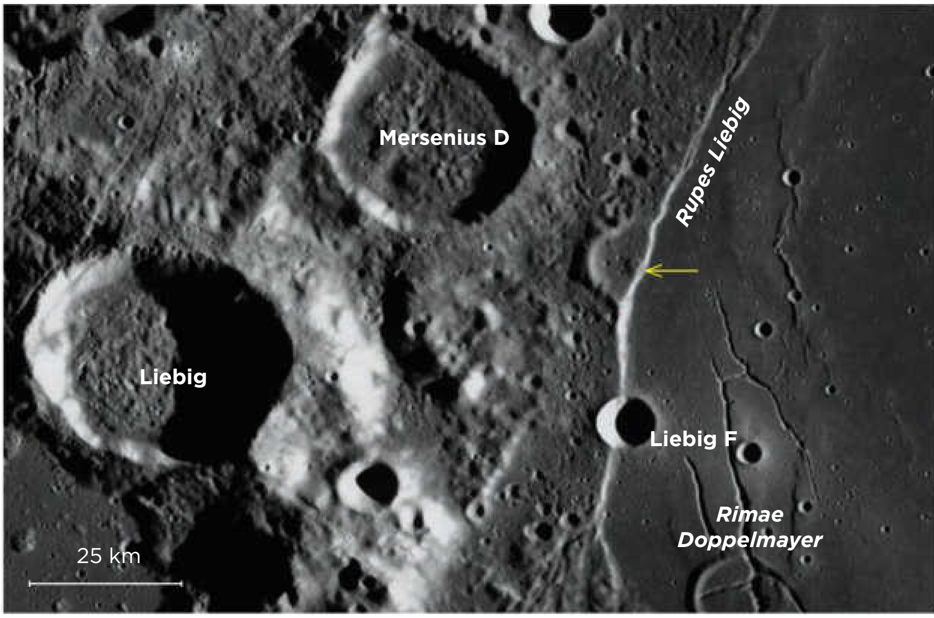
Loewy along the eastern shore. To the north, Gassendi's walls also dip inward. Perhaps the basin floor had a sloped, saucer shape after its formation, or perhaps the inward tilt occurred as the basin filled with lava. Whatever the reason, these craters tilted inward and the ejecta around them became buried under flows that erupted later.

Cracking under pressure

The massive mare slab also sank under its own weight and caused fracturing around its eastern edge, producing three parallel arc-shaped rilles — the Rimae Hippalus. Other basins have such extension cracks, but few are as large and dramatic as these. Also look for a family of three or four mare ridges along the eastern interior of the mare that are best seen with sunrise illumination (when the Moon's phase is waxing gibbous). These formed as the basin's centre subsided, which forced the solidified mare flows to fit into a smaller volume. The kilometre-thick slab accommodated this squeezing by fracturing multiple times. Some parts of the mare slid up over adjacent parts, creating the mare ridges.

Use high magnification to observe that the western edge of the mare, just inside the Percy Mountains, is sharply bounded by a fault that separates the smooth lava from older rugged terrain to the west. Farther south, along the mare's western margin and inward from the 39-km-wide crater Liebig, the fault boundary becomes detectable again — at least near local sunrise or sunset, when the scarp's higher western face is starkly illuminated or shadowed, respectively. Rupes Liebig truly is a fault, as dramatically illustrated by an older, 10-km-wide crater just east of Liebig that's been sliced in half. Its eastern side dropped down and became smothered by mare lavas, making its eastern rim completely invisible. Just to its south, look for a younger, 8-km crater gouged out right on the fault scarp. Topographic data from the Lunar Reconnaissance Orbiter (LRO) show that the eastern rim of this crater is 500 m lower than the western rim. That's not at all obvious telescopically.

When you observe Humorum near full Moon, note that the area around Rimae Doppelmayer in the southwestern corner is much darker than most of Mare Humorum. Spectral studies confirm that this dark material consists of pyroclastic glass beads that must have been tossed out of a volcanic vent. But no vents are visible, even in high-resolution LRO images, so the explosive activity that laid down the dark deposits probably came from eruptions along the rille's 300-km length. In fact, the rille runs down the middle of a wide ridge, 7 to 8 km across, that rises up to 100 m above the surrounding mare. This is probably the pile of pyroclastic material that accumulated around the long eruption fissure. Sadly, we're about 3.5 billion years too late to witness the fireworks! ✦



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This close-up of western Mare Humorum shows how the long fracture Rupes Liebig has sliced through an unnamed crater (arrow). Its right (eastern) half dropped down and was later covered with lava flows.


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SISSY HAAS

EPSILON BOÖTIS The component stars of the bright double Epsilon Boötis, with a separation of 3.0″ and a magnitude difference of 2.0, can be split with 60 mm of aperture.

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The Uneven Double Stars Project

Contribute your data to this ongoing observing endeavour.

Want something new to do with your telescope? If I can interest you in joining our project, please know we'd love to have your help. And now with that much said, let me back up and start at the beginning.

You and I know the sky is filled with double stars. Almost every time we study star fields with our telescope, we'll see that one of the stars is actually two stars, barely separated with magnification. If you've seen any of the showcase pairs, you know they can have breathtaking colours. But we don't always know that we'll see a double star, even when the star is known to be one. If a pair is made of stars not fainter than 6th magnitude and not drastically unequal in brightness, you can use the Dawes limit as the guideline for your aperture: 116 divided by the aperture in mm = the smallest separation in arcseconds (″) it is possible to resolve. For example, the Dawes limit for my 60-mm telescope is 1.9″, since 116/60 = 1.9. Any pair at least this wide should look double through my 60-mm, so long as it's not faint or unequal. Of course, my 60-mm may not perform at the Dawes limit because of bad weather or other factors, but the rule holds true in ideal observing circumstances.

But what if the stars are very unequal in brightness? What's the limit of my telescope then? There have been many formulae published over the years devoted to answering this question. It was the subject about which I was most frequently asked when I had a regular column in this magazine, and Chris Lord of the United Kingdom spent 20 years of his life on it. He gathered personal observations for many years and used his background in mathematics to extrapolate a predictive formula between aperture and separation for unequal double stars; all it requires is a ruler and chart.

Test pairs by separation and magnitude difference

Separation	ΔM = 1.0	ΔM = 1.5	ΔM = 2.0	ΔM = 2.5	ΔM = 3.0	ΔM = 3.5	ΔM = 4.0
1.0″	Σ2054 (Dra) 130-mm?	Hrg 47 (Car) no data	Σ2403 (Dra) no data	41 Oph no data	42 Ori 200-mm?	8 CMa no data	69 Her no data
1.5″	Dun 39 (Car) no data	Hu 544 (Per) 80-mm?	θ Gru no data	Σ2303 (Ser) 150-mm?	β 67 (Cyg) no data	90 Her 150-mm?	no star —
2.0″	33 Ori 80-mm?	μ Cyg 60-mm	49 Leo 100-mm	κ Lep 130-mm	3 Mon 200-mm	Σ1171 (Cnc) no data	Hu 1136 no data
2.5″	CapO 16 (Cir) no data	Σ389 Cam 80-mm	38 Lyn 80-mm	no star —	H Vel no data	h3874 Pic no data	no star —
3.0″	17 Dra 60-mm?	CapO 9 (Vel) no data	ε Boo 60-mm	ψ Cyg 80-mm?	23 Aql 100-mm	π Cap 100-mm?	ψ Ori 100-mm
3.5″	90 Leo 60-mm?	Σ2671 (Cyg) 60-mm	Σ1881 (Vir) 100-mm	See 180 (Cen) no data	h4178 (Car) no data	h5188 (Sgr) 100-mm?	no star —
4.0″	ρ Her 60-mm	65 UMa 80-mm	Σ750 Ori 80-mm	Σ2958 (Peg) 90-mm?	Σ1878 (Dra) 100-mm	5 Aur 100-mm?	Σ3116 (UMa) 100-mm?

And now with all *this* said, I'll go back to the first sentence and talk about the Binary Star Observing Project and the Uneven Double Stars Project. Like Lord, we're looking to find the smallest realistic aperture for a specific separation and magnitude difference. But we're simply gathering observations: no predictive formula is intended from them. We've determined test pairs in increments of 0.5, starting at 1.0. All we ask you to do is look at them — as few or as many as you have time for — and see whether or not the pair splits with your aperture. That's it!

Even if our findings prove redundant to what Lord found or predicted, they'll reinforce his study and won't be wasted. What we'd like to have is so many observations, from so many different observers, that we can give a specific aperture for a specific separation/magnitude difference without fear of being wrong. We can already do that for a bright pair that is 3.0″ apart and unequal by 2.0 magnitudes, using Epsilon Boötis as the case example.

We have 17 confirmations, from many different observers, that it can be split with 60-mm instruments, and 12 confirmations that it splits with still smaller apertures. Thus, 60 mm is a confident aperture to give for splitting. We have similar overwhelming reports that 100 mm will split a separation of 2.0″ and inequality of 2.0 magnitudes (here, 49 Leonis is our test pair).

The table on page 61 shows other test pairs of our project and what we can report at this time. The apertures with a question

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49 LEONIS The component stars of double star 49 Leonis, with a separation of 2.0″ and 2.0 difference in magnitude, can be split with 100 mm of aperture.

Detailed data for the southern declination test pairs

Star	Constellation	RA	Dec	Separation	M1 – M2	ΔM
γ Cae	Cae	05h 04.4m	-35° 28′	3.2″	4.7 – 8.2	3.5
κ Lep	Lep	05h 13.2m	-12° 56′	2.0″	4.4 – 6.8	2.4
42 Ori	Ori	05h 35.4m	-04° 50′	1.1″	4.6 – 7.5	2.9
Σ 750	Ori	05h 35.5m	-04° 22′	4.1″	6.4 – 8.4	2.0
3 Mon	Mon	06h 01.8m	-10° 36′	1.9″	5.0 – 8.0	3.0
Σ 3116	CMa	06h 21.4m	-11° 46′	3.9″	5.6 – 9.7	4.1
h 3874	Pic	06h 32.0m	-58° 45′	2.5″	5.6 – 9.3	3.7
8 CMa	CMa	06h 37.9m	-18° 14′	1.1″	4.6 – 8.2	3.6
Δ 39	Car	07h 03.3m	-59° 11′	1.4″	5.8 – 6.8	1.0
CapO 9	Vel	08h 52.7m	-52° 0.8′	2.9″	6.6 – 8.2	1.6
H Vel	Vel	08h 56.3m	-52° 43′	2.6″	4.7 – 7.7	3.0
h 4178	Car	09h 04.8m	-57° 51′	3.4″	6.5 – 9.7	4.1
Hrg 47	Car	10h 03.6m	-61° 53′	1.2″	6.3 – 7.9	1.6
See 180	Cen	13h 31.4m	-42° 28′	3.6″	6.7 – 9.2	2.5
CapO 16	Cir	15h 29.5m	-58° 21′	2.4″	7.0 – 8.0	1.0
41 Oph	Oph	17h 16.6m	-00° 27′	1.0″	4.9 – 7.5	2.6
Σ 2303	Ser	18h 20.1m	-07° 59′	1.6″	6.6 – 9.2	2.6
h 5188	Sgr	20h 20.5m	-29° 12′	3.6″	6.7 – 10.0	3.4
ϖ Cap	Cap	20h 27.3m	-18° 13′	3.2″	5.1 – 8.5	3.4
θ Gru	Gru	23h 06.9m	-43° 31′	1.5″	4.5 – 6.6	2.1

Right ascension and declination are for equinox 2000.0.

mark mean that we have several observations but not yet enough to give a confident aperture.

You can see where we still need help. We need it the most from Southern Hemisphere observers. You might also notice something else: the numbers on our chart don't always seem to make sense. Take Mu (μ) Cygni, for example, a pair that my notes call "bright yellow" and "pale plum" and split by the "tiniest sliver of space" with my 100-mm at 200×. It's 2.0″ apart and unequal by 1.5 magnitudes. Our reports show that it splits with just 60 mm of aperture, while the equally separated but *less* unequal 33 Orionis needs 80 mm. It may be that we need more observations, but it also could be that Mu Cygni, made of brighter stars, is easier to see with a little 60-mm scope.

Another problem we've run into is the limiting magnitude. (This refers to the faintest magnitude a telescope can see.) That's because our test pairs that are 4.0″ wide and unequal by more than two magnitudes have 9th- to nearly 10th-magnitude companions. A star this faint is hard to observe with less than 100 mm, even when it stands alone, unless the sky is quite clear. That added complication shows up in our findings for **Σ**2958 (Struve 2958) in Pegasus: it's wider than Psi (ψ) Cygni and no more unequal, but requires at least as much aperture. I need 100 mm to see its companion, and even with this much, all I see is a dim, nebulous globe beside a muddy white star. I can't even see the companion of 5 Aurigae with that aperture, but Bill Boublitz of Hanover, Pennsylvania, an enormous contributor to our project, can, describing it as "a ghost of a thing... a faint, tiny, ice-blue point."

Still another problem we have found is the tiny 1.0″ or 1.5″ separations for pairs like **Σ**2403 in Draco or **β**67 (Burham 67) in Cygnus. A pair this close should need at least 125 mm and a scope that gives razor-sharp images, even if it was made of equals; an unequal pair should need still more aperture, and scopes larger than 125 mm are greatly affected by the sky. We just don't have enough observers with large refractors or Maksutovs and excellent skies. Boublitz was able to split both these pairs, as well as equally hard 90 Herculis, with his 178-mm Maksutov. He describes Σ2403 as "white [and] orange-grey, split was easy [at 150×]." He saw **β**67 as a "white star" with a companion "that was quite dim without any vivid color . . . just sort of grey," but added that it "shows some orange-brown at times." 90 Herculis appeared as a "golden star with an orange fringe," with a "sparkling medium blue diamond" next to it, and he considered it a "very tough object," even for his 178-mm.

A much easier close pair that's also easy to find is **Σ**2054 in Draco: it's in the same low-power field with Eta (**η**) Draconis. My logbook says I needed 350× with my 125-mm refractor to "just barely" split it. At the opposite end of the difficulty scale are Rho (**ρ**) Herculis, 17 Draconis, and **Σ**2671 in Cygnus. I'm sure these are pairs for the smallest telescope, but we need more confirmations of this for 17 Draconis. All are naked-eye stars easy to find and all split easily in my 60-mm refractor. Rho Herculis was among the first double stars I ever observed, many decades ago. I thought both stars looked white, but 19th-century observer Admiral Smyth considered the companion "pale emerald." 17 Draconis appears as a wide double star through a finder scope, comprising 16 and 17 Draconis. I see 17 as "yellow-tinted white and pale white," but the classic 19th-century observer T. W. Webb called the companion "pale lilac." My notes call Σ2671 a "bright white star with a grey smoke ball close beside it."

Psi (ψ) Cygni is another fine naked-eye star that some of our observers have split with just 60 mm, but not me! My only notes are from my 125-mm, through which the pair appeared "brilliant yellow and ocean blue." Admiral Smyth described it as "bright white [and] lilac," however.

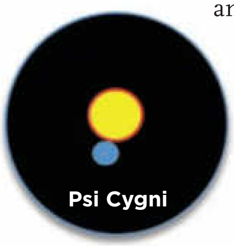
Hu 544 in Perseus shares a low-power field with Alpha Persei. Boublitz found it "challenging" to split with his 101-mm; he calls it "a tiny blue dot below a blue-white primary [star]." He found nearby **Σ**389 in Camelopardalis a "striking and lovely pair . . . cream white and green" as viewed with his 178-mm, but saw "hints of orange" for the companion with his 101-mm.

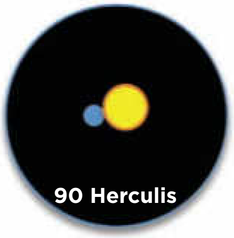
For Northern Hemisphere observers, Pi (**π**) Capricorni and h5188 in Sagittarius are about as well placed as they're going to get. I found Pi Cap radiant white and pure silver, but Boublitz saw the companion as "ruddy red or rust orange." He described h5188 as a group of stars, because he saw its very wide, faint companions along with the main AB pair that's our test object. Our other test pairs visible now are deep in the Southern Hemisphere. I can't tell you much about them from our reports, because we have so few southern observers.

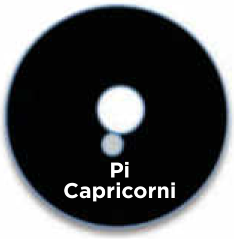
We'd love to have you join us! To find out more about our project, visit **http://is.gd/HaasProject** and **http://is.gd/udstars**. You can send e-mail to **has103@comcast.net**, or write to me:

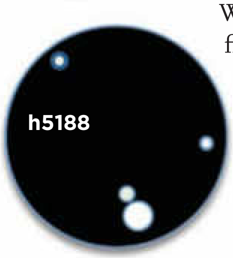
Sissy Haas
823 Reamer Ave. Ext.
Greensburg, PA 15601
USA

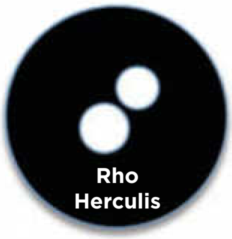
Sissy Haas lives in a small city in western Pennsylvania at the end of an unlighted dead-end street, but whether her sky is dark depends on who rents the house next door.











ALL SKETCHES BY THE AUTHOR

The perfect planetary 25-cm

This home-built scope combines transportability and superb performance.

As Leonardo da Vinci once observed, "art is never finished, only abandoned." To some extent, this is also true of home-built telescopes. We often abandon a project when it's reached a stage of completion advanced enough to be functional. Usually we do so knowing we'll return to it again and again to make modifications or add features, as our needs and desires evolve with experience. And so it is with this issue's telescope. "What you see here is an ongoing project with an accumulation of improvements to a telescope I began designing seven years ago," says Ken George.

Like many telescope makers, Ken started off with a specific goal in mind. "From the beginning, this was meant to be my ultimate planetary dream scope, with a focus on portability while preserving optimal performance," he says.

The scope's high-performance foundation is its 25-cm, f/7 primary mirror, crafted by the skilled hands of optician Carl Zambuto. And that was just the start. "A lot of reflectors are plagued with mediocre contrast, diffraction spikes, and thermal issues," he notes. "Over the years, I tackled each of these one by one." Among his many refinements, the scope features a curved-vane spider to eliminate diffraction spikes, a trio of variable-speed fans to control the primary mirror's thermal behaviour, and felt flocking to tame stray light.

A 25-cm f/7 Dobsonian isn't a scope you see every day. One that can be transported easily is even rarer. Telescope maker Ken George built this instrument and optimised it for high-quality planetary viewing and quick-and-easy field setup when participating in public observing events.

KEN GEORGE

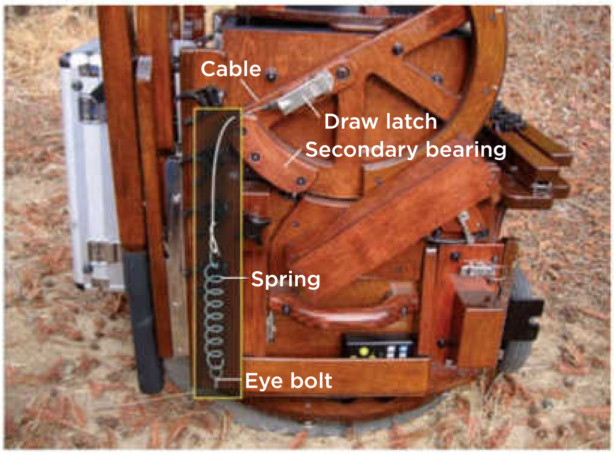
Form follows function, so the slightly unorthodox appearance of Ken's scope reflects his desire to make it easy to transport and quick to set up. "I've been active in the local astronomy community for many years and regularly set up my telescope for public viewing events at libraries, schools, museums and parks," he says. "As you can imagine, efficient transport and quick assembly are important considerations."

Most portable Dobs are a pain to set up in the field. They usually require multiple trips back and forth from the car as each component is unloaded and assembled. The pain is compounded if you end up having to park a great distance from the observing area. Ken wanted to avoid that, so he built his telescope as an all-in-one unit that wheels in and out of his hatchback on a pair of 3.5-kg folding aluminium ramps. The unit incorporates everything he needs — from truss poles to eyepieces — with an integrated wheelbarrow setup that enables him to quickly and easily move the scope from his car to an observing spot in a single trip. Five minutes later, it's a sky-ready instrument.

How does it work? There are three key features. First are the previously mentioned built-in, double-folding 'wheelbarrow' handles permanently attached to the rocker box. As Ken describes, "the primary fold is connected to the rocker box and utilises a pair of 90°, self-locking shelf brackets, while the secondary fold has a standard gate hinge and is held straight by a heavy-duty three-axis locking latch."

KEN GEORGE

Everything he needs for a night of observing is integrated into the telescope — including foldaway 'wheelbarrow' handles and wheels. The scope's truss poles and eyepiece box are attached to the rocker box during transport.



The scope features an ingenious spring counterweight system.

Second, and equally ingenious, are the two wheels mounted on the front of the rocker box. "Removable wheels are a hassle, and permanently fixed ones often get in the way during observing," he notes. "Each wheel on my Dob pivots on a very heavy-duty door hinge and locks into the open position using two metal, quick-release locking latches."

Lastly, Ken came up with a simple means of transporting the scope's four truss-pole pairs. He used twelve foldaway fish-pole clips affixed to the rocker box. On each side, four clips are attached directly to the rear of the rocker box, while two more are mounted on a pivoting arm that swings out from the front of the rocker box. Each individual clip folds flush against the scope to prevent clothing from snagging on them.

"This telescope performs and transports better than I ever expected," Ken says. "Designing and building it has taught me much about the finer details of optimising portability and maximising planetary observing performance."

To ensure a compact configuration that would fit into his car, Ken needed a low-profile rocker box. But how to accomplish that goal? The scope has two significant issues. First is its 177-cm focal length. The longer the tube, the farther the balance point must lie from the back end. The second is that the scope is front-end heavy. "A binoviewer is the one accessory I'll never part with," Ken says. That accessory, plus two eyepieces, adds 1.7 kg to the front end. Include a dew heater and a big finderscope, and the secondary cage now tips the scales at 3 kg.

The net result is that a whopping 16 kg of counterweight would be required to balance the tube. "That kind of extra weight on a portable scope just isn't practical," Ken states. "But after reading about telescope makers who utilised springs in place of counterweights, I decided to give the idea a shot."

The instrument's spring counterweight setup is mostly concealed (which is one of its nice features) and consists of only a few parts, most of which can be found at a well-stocked hardware store. The scope has one complete spring system on each side. As the photograph shows, one end of the spring is attached to an eye bolt mounted on the bottom of the rocker box. At the other end of the spring is a length of nylon-coated, braided wire that passes over a small secondary bearing with a guide groove cut into it. The other end of the wire is affixed to a quick-release draw latch. "This fitting allows me to quickly and easily detach the rocker box from the mirror box, and dial in just the right amount of spring tension by adjusting the hook-arm length," Ken notes.

The most important component is, of course, the spring. Choosing the correct one means juggling several variables. To begin, you have to figure out how much force your scope will require to achieve balance. Once you know that, you can use basic torque calculations to narrow down your selection. As Ken says, "you find a spring that has the right counterweight force, diameter, stretch length (both free and maximum), and wire diameter (for overall strength) for your particular scope." He tried several springs and selected the one that gave his scope's motions the best feel, demonstrating that even after all the calculations have been made, some experimentation is still valuable.

"With only a few kilograms of hardware, I successfully eliminated more than 16 kg of counterweight," Ken reports. That's a big difference in any size telescope. If this all sounds like the proverbial free lunch, to some extent it is. There are limits to how far you can push the concept. While a properly implemented spring counterweight system will make your scope move as if it's perfectly balanced, you have to keep in mind that it's not *really* balanced. In other words, it's a 'virtual' counterweight — if you make the front of the scope heavy enough, or the mount's ground board too small, the scope will tip over, spring counterweight or not! That said, the benefits Ken describes are substantial and worthwhile.

Of course, as is the case with the whole telescope, refinements are possible for the counterweight system. Ken says, "In the future, I might simplify the system by positioning each cable along the top edge of the side bearings, eliminating the need for the secondary bearings entirely."

If you're interested in learning more, you can e-mail Ken at **myinem@yahoo.com.** ✦

Bargain scopes for beginners

We put three entry-level telescopes through their paces.

How much does a decent beginner scope cost? There are plenty of good choices for around $550, and the options are almost limitless if you're willing to spend more. At the opposite extreme, it's possible to buy a good telescope for as little as around $150. But $150 scopes have very small apertures and limited capabilities.

Things change when you move up a notch in price. If you shop carefully, a $300 telescope can provide very good views of planets and deep sky objects. But how do telescopes in this same price range compare?

While searching for good telescopes in the $300 price range, we evaluated many scopes and have included three of them here — the Meade Infinity 90mm altazimuth refractor, the Orion StarBlast 4.5 reflector and the Astronomers Without Borders' OneSky reflector. One of them stood out — the Meade Infinity 90 Refractor. With a 90-mm f/6.7 achromatic objective lens, it offers a fair amount of aperture with a rich package of accessories.

StarBlast versus OneSky

The StarBlast and OneSky are strikingly similar. Both are small Newtonian reflectors, though the OneSky's 130-mm f/5 mirror gathers 30% more light and has a 44% longer focal length than the StarBlast's 114-mm f/4 mirror. Their mounts are identical, requiring a table or similar support to hold them.

The most obvious difference between the StarBlast and OneSky is that users can collapse the OneSky's tube for convenient transportation. This also enables it to incorporate a much longer focal length into a slightly smaller package.

The OneSky's open tube works well under dark skies. But the view is plagued by reflections that dramatically decrease the contrast of deep sky objects when the scope is used near bright lights. You can fix this by constructing a simple shroud out of lightweight foam material (see **http://is.gd/GMPMMW**).

The StarBlast has a standard rack-and-pinion focuser. While this would be adequate for many scopes, it's slightly crude with the this telescope's f/4 focal ratio, in which a tiny change in eyepiece position causes a big change in focus. The OneSky's simple helical focuser is easier to fine-tune with the lightweight eyepieces supplied with the scope.

Both optical tubes slide back and forth to achieve balance. The OneSky uses a Vixen-style dovetail bar that holds the tube at a fixed orientation, placing the focuser about 20° left of vertical. This requires you to stand behind the scope when aiming high in the sky. The StarBlast uses tube rings that allow you to rotate the tube and adjust the eyepiece to a comfortable angle.

A OneSky we saw in 2014 had a very good mirror, as does the unit that I borrowed for this review, suggesting that this is typical for the model. StarBlasts, by contrast, have shown considerable variation in optical quality. My own StarBlast has a good mirror, though not as good as the one in the OneSky. The best StarBlast mirrors are excellent and the worst are merely acceptable — fine for deep sky observing but less-than-ideal for viewing the Moon and planets.

All three of the telescopes include eyepieces that are variants of the three-element Kellner design. Their optical quality is very similar, as I verified by using each of the eyepieces with all of the scopes. The design works significantly better in the OneSky than in the StarBlast. The eyepieces are quite sharp in the centre in both scopes, but stars are severely distorted near the edge of the field with the StarBlast due to its very fast f/4 focal ratio. The fraction of the field that's truly sharp is much larger in the f/5 OneSky.

To achieve high magnifications, the StarBlast needs short-focal-length eyepieces, which tend to have less eye relief. I found my eyeball uncomfortably close to the glass when using the stock 6-mm eyepiece. On the flip side, the StarBlast's short focal length gives it an expansive field of view when used with premium eyepieces: a 24-mm wide-field design produces a magnificent 3.4° field, big enough to take in the entire Veil Nebula.

All three scopes have variable-intensity red-dot finders. These work much better than the low-quality finderscopes that used to be included with budget-priced telescopes, but they do have their quirks. The electrical contacts

MEADE INFINITY 90MM ALTAZIMUTH REFRACTOR

Meade's Infinity 90mm Altazimuth Refractor has enough aperture to produce satisfying views of the Sun, Moon and planets, as well as bright deep sky objects and double stars.

ORION STARBLAST 4.5 ASTRO REFLECTOR TELESCOPE

For more than a decade, Orion's StarBlast has been one of the best 'bang-for-the-buck' telescopes, featuring a 11.4-cm parabolic mirror in a compact alt-az configuration.

ASTRONOMERS WITHOUT BORDERS ONESKY REFLECTOR

The Astronomers Without Borders OneSky Reflector packs a moderately large 13-cm aperture mirror into a collapsible tube design.

All three telescopes include enough eyepieces to provide satisfying wide-field and close-up views of targets, and the Infinity 90mm includes a 2× Barlow lens (not shown). The StarBlast and OneSky both come with useful collimating tools.

WHAT WE LIKE:

Good high power with stock eyepiece

No collimation or cool down required

Good slow-motion controls

WHAT WE DON'T LIKE:

Awkward when pointed near zenith

Poor-quality Barlow lens

WHAT WE LIKE:

Very easy to use

Adjustable eyepiece angle

WHAT WE DON'T LIKE:

Requires table or other stand

Not great at high power

WHAT WE LIKE:

Very easy to use

Good high power with supplementary Barlow

WHAT WE DON'T LIKE:

Requires table or other stand

Awkward eyepiece angle

Slightly crude helical focuser

tend to be a little balky, sometimes requiring jiggling the battery case before the finders light up.

Good as they are, the StarBlast and OneSky have a number of limitations. Most obviously, they require a table or similar support. Some users have had good results using milk crates, buckets or other objects. An ideal solution is to build your own support (such as the one shown on the next page) or the more robust model described under 'DIY Improvements' at **eyesonthesky.com**.

One big consideration for beginners is that all reflecting telescopes require collimation. To their credit, both the StarBlast and OneSky ship with centre-spotted mirrors and simple but effective collimation tools — features often omitted with scopes that cost several times as much. Using these, collimation is fairly quick and easy once you've learned to do it, but it's still a major psychological hurdle for most beginners.

Reflectors also take a fair amount of time to cool down to the ambient temperature before they deliver truly sharp images. And they're problematic for viewing terrestrial subjects because they show everything upside down.

Refractors sidestep all of these problems. They require no collimation, cool down in a matter of minutes, and they're typically used with star diagonals that show objects right-side up. A small refractor is more appropriate than a reflector for many beginners despite the fact that you get significantly less aperture for any given amount of money. Let's take a quick look at our refractor before discussing how all three scopes perform under the night sky.

Although the OneSky has both a larger aperture and longer focal length than the StarBlast, it collapses into a somewhat smaller package for convenient storage and travel.

The OneSky works best on a standard-height table or similar support. The focuser's fixed position forces users to stand behind the instrument when viewing near the zenith.

ALL PHOTOGRAPHS TAKEN BY S&T: SEAN WALKER

The Infinity 90

The Meade Infinity 90 offers a respectable aperture at an attractive focal ratio. F/6.7 is short enough to give the telescope a wide field of view and a reasonably compact tube. But it's also long enough to avoid the extreme false colour that sometimes comes with inexpensive achromatic objectives. An unusual feature of the Infinity 90 is that it includes a 90° image-erecting prism that shows objects in correct orientation rather than mirror-reversed as with most refractors used with a conventional star diagonal — very handy for terrestrial viewing. Unlike some inexpensive image-erecting prisms, this one has very good optical quality.

The Infinity 90's biggest shortcoming is its mount. It's quite stable and vibration-free unless you're using it in a strong wind — far superior to the wobbly mounts supplied with most low-cost 60-mm refractors. But it's awkward to use. The scope isn't counterbalanced, so the altitude bearing needs a lot of friction to prevent the scope from toppling backward when pointed high in the sky. It's impossible to make fine adjustments with such stiff bearings, though the long handle supplied with the mount helps a lot. In practice, I almost always needed the slow-motion controls to centre my target. This two-step process makes it frustrating to browse galaxy fields or the Milky Way with the ease and grace of the other two scopes.

The slow-motion controls are very handy for keeping the planets centred as they drift across the field at high power. But they have a limited range of motion, so they eventually 'bottom out'. Then you have to reset them, re-centre the planet and start over again.

The Orion StarBlast is extremely comfortable to use when seated, though a small table or other support is necessary to perch the scope at a comfortable height.

The refractor's tripod is also fairly short. That keeps it both stable and light; the entire assembled scope is easy to carry in one hand. But even with its legs fully extended, I had to sit on a low footstool to view through the eyepiece when the scope was aimed high in the sky. It's exceedingly awkward to view through the red-dot finder in this position, so I avoided targets within 30° of the zenith.

The Infinity 90 costs a little more than the OneSky and StarBlast, but that's offset by the inclusion of an extra eyepiece offering 95× magnification, making it the only one of the scopes that can provide detailed views of the planets without a supplementary eyepiece or 2× Barlow.

The Infinity 90 does in fact include a 2× Barlow. Unfortunately, it exhibits strong false colour everywhere except the centre of the field. But even without the Barlow, the Infinity 90 has the most versatile eyepiece collection of all the scopes.

All three scopes have eyepieces with thoughtfully selected focal lengths, as shown in the table below. Low power is 26× for the StarBlast and OneSky and 23× for the Infinity 90. These are ideal magnifications for viewing large star clusters such as the Pleiades and Beehive and also very good for star-hopping. Medium-high is 75× for the StarBlast, 65× for the OneSky and 67× for the Infinity 90 — excellent for close-up views of deep sky objects, but a little low for viewing the Moon and planets.

Under the stars

When I tested the StarBlast, OneSky and Infinity 90, I mostly restricted myself to using the stock eyepieces, sometimes with the addition of my own 2× Barlow. I used one or more of the scopes on most clear nights in May 2015, viewing the Moon, Venus, Jupiter, Saturn and a wide range of deep sky objects. I compared the scopes side by side on specific targets and also used each scope by itself for an entire evening to get a sense of its overall feel.

The planets are particularly attractive targets for beginners — and challenging targets for small telescopes. Even at medium-high magnifications (67× to 75×), all three scopes easily displayed the phase of Venus, the two main belts of Jupiter and gorgeous views of Saturn's rings. My best views of the planets came at 95× with the 6.3-mm eyepiece on the Infinity 90, 112× with my own 4-mm eyepiece on the StarBlast, and 130× using the OneSky with its 10-mm eyepiece plus a 2× Barlow. At these magnifications, I could see Jupiter's Great Red Spot, shadow transits of its moons and the Cassini Division in Saturn's rings when atmospheric steadiness allowed. These features were quite obvious through the OneSky, a little harder to pick out through the Infinity 90 and problematic with the StarBlast.

I also tried the StarBlast at 150× with the stock 6-mm eyepiece and a 2× Barlow, but I found the scope very hard to focus at this magnification, and I saw little improvement over the view at 112×. One problem with the StarBlast is that the 'sweet spot' where the view is truly sharp is relatively small, requiring you to nudge the scope quite frequently.

At the opposite extreme, the Infinity 90's view is sharp all the way to the field stop; the 3-element eyepieces work very well at f/6.7. Together with the slow-motion controls, this makes it very easy to track the planets. Like all fast achromats, the Infinity 90 shows violet halos around the Moon and

TELESCOPE SPECIFICATIONS

	Infinity 90	StarBlast	OneSky
Aperture	90 mm	114 mm	130 mm
Focal length	600 mm	450 mm	650 mm
Focal ratio	f/6.7	f/4.0	f/5.0
Weight	5.4 kg	5.9 kg	6.7 kg
Low mag.	23×	26×	26×
Medium mag.	67×	75×	65×
High mag.	95×	—	—

Optical specifications are based on advertised data. Weights are as measured.

The Equatorial StarBlast

The 11.4-cm StarBlast is available with a lightweight equatorial mount, which I also used during this review. I'm not usually a fan of ultralight equatorial mounts, but this one works quite well with the StarBlast due to the optical tube's extreme shortness and light weight.

Equatorial mounts can be daunting to beginners because of their complexity. But they can also be used in alt-azimuth mode by setting the altitude scale to 90°, and in that configuration they're just as simple as tabletop mounts, with the added benefit of slow-motion controls.

planets, but planetary views are otherwise attractive and detailed.

Under the semi-dark skies of my country home, all three scopes performed admirably on deep sky objects, given their apertures. They showed all of the Messier objects with ease, and provided detailed views of many. The OneSky wins the prize on globular clusters, but all three scopes resolve half a dozen to a dozen stars in M4, M22 and M5. The Infinity 90 is best for large open clusters such as M44, the Beehive, due to the scope's sharp field with the stock low-power eyepiece. But the OneSky is also superb, and the StarBlast isn't far behind. On galaxies and nebulae, the scopes perform in aperture order with the best views through the largest aperture.

The OneSky's collapsible tube is susceptible to stray light that can compromise its otherwise excellent views. The author made this simple shroud out of a piece of lightweight foam that can be found at most arts and crafts stores.

Roughly aiming the Meade Infinity 90 refractor is aided by using the long handle at the back of the tripod. Targets can then be centred with the slow-motion controls.

Conclusions

The OneSky probably ranks highest among these scopes because it provides the best overall views both of planets and deep sky objects. But it does require a supplementary 2× Barlow to show the planets in detail, and its focuser works poorly with heavy eyepieces. Moreover, each of the other scopes has advantages that might be compelling in specific circumstances.

The StarBlast has superb ergonomics due to its rotatable tube; it's ideal for viewing from a seated position. Deep sky enthusiasts will also appreciate its extraordinarily wide maximum field of view when used with an additional 24- or 25-mm eyepiece. It's the weakest of the three on planets, but still comfortably ahead of most telescopes in its price class.

The Infinity 90 is best for those who want quick looks at the Moon and planets because it requires no collimation, cools down in a matter of minutes, and offers views not far behind the OneSky's. And it's completely self-contained, needing no table or stand to support it. But its alt-azimuth mount isn't well suited to browsing the deep sky.

While each of these telescopes has some flaws and limitations, they're all easy to use and a joy to look through. Best of all, they offer outstanding value for their amazingly low prices. ✦

Left: **The Infinity 90 includes a quality image-erecting prism that makes the scope useful for both terrestrial and astronomical observing.** ***Middle:*** **Even when fully-extended, the Infinity 90 tripod is short. While this provides a stable view at high magnification, a low stool or observing chair is required for comfortable viewing in most positions.** ***Right:*** **Aiming the refractor at targets anywhere near the zenith is awkward, due to the position of the red-dot pointer. A better placement for the finder would be near the objective lens.**

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Alan MacRobert
Book Review

The next great deep sky handbook

Annals of the Deep Sky: A Survey of Galactic and Extragalactic Objects

I've been waiting since the 1980s. Now it's happening. We're getting an expanded, updated successor to the legendary *Burnham's Celestial Handbook*.

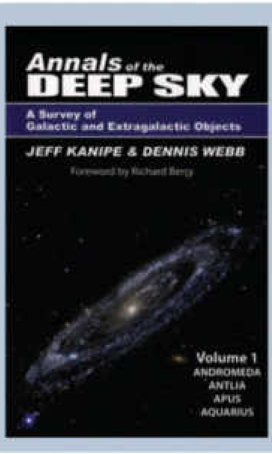
Someday, I was sure, the next heir would be born to a long and distinguished literary line founded 171 years ago: big, chatty, history- and science-rich guidebooks for telescope enthusiasts, arranged alphabetically by constellation. Admiral William Henry Smyth founded it in 1844 with *The Bedford Catalogue* (Volume 2 of his *A Cycle of Celestial Objects*); it's still in print. Carrying the line forward were the Reverend T. W. Webb's *Celestial Objects for Common Telescopes* (first published in 1858); William Tyler Olcott's slimmer *A Field Book of the Stars* (1907, with many editions following); C. E. Barns's *1001 Celestial Wonders* (1929); Professor E. J. Hartung's *Astronomical Objects for Southern Telescopes* (1968) and then *Burnham's,* biggest of all, published from 1966 to 1978 — full of observational details, science, poetry and astronomical history in three volumes totalling 2,138 pages.

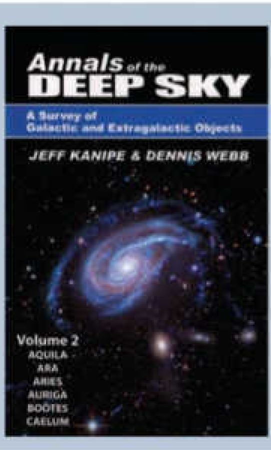
Annals of the Deep Sky is even more ambitious. Authors Jeff Kanipe and Dennis Webb have made a long-term commitment to it for the astronomical book publisher Willmann Bell. The first two volumes are out, covering the first 10 of the 88 constellations, Andromeda through Caelum. Volume 3 with five more, Camelopardalis through Canis Minor, should be out in January.

Volume 1, like *Burnham's,* begins with a roughly 100-page introduction to the astronomy that an amateur really needs to know: the celestial sphere and the sky's motions, the magnitude system, angular measures and so on, along with lots about the various types of objects to be seen through amateur scopes.

Then the constellations begin. Andromeda runs to 92 pages, compared to 57 sparser pages in *Burnham's*. Only 17 telescopic targets (or groups of targets) in Andromeda are treated, but with extraordinary depth and interest. *Annals* isn't meant to be a complete deep sky list. For that, get Kepple and Sanner's *The Night Sky Observer's Guide* (listing 7,935 objects, many with paragraph visual descriptions and a photo or sketch), or the modern edition of Hartung's *Astronomical Objects for Southern Telescopes*, or the *Uranometria 2000.0 Deep Sky Field Guide* (with dense data tables and one-line descriptions for 30,000 objects). Instead, *Annals* dives deep into a constellation's primary targets and explores around — telling not just what they look like, but their history, lore and especially their scientific underpinnings and the astrophysics they illuminate.

There's poetry too, and biography. Every constellation chapter ends with an innovative section called 'The Third Dimension,' following outward a fan of space that spans the width of the constellation and extends past nearby stars to structures in the local and distant Milky Way, then to galaxy groups, clusters and voids.





Jeff Kanipe and Dennis Webb
Willmann Bell, 2015+

Vol. 1: 358 pages,
ISBN 978-1-942675-00-6
US$24.95, paperback.

Vol. 2: 342 pages,
ISBN 978-1-942675-01-3
US$24.95, paperback.

Simon Newcomb's provocative 1878 essay on the 'Andromeda Nebula' (M31) gets a page to itself, with a period engraving of the 26-inch U.S. Naval Observatory refractor that Newcomb used. Later in the M31 entry we learn the recent story of the galaxy's complex multiple nucleus, partially resolved by the Hubble Space Telescope (a photo is included) and analysed by cutting-edge techniques. The nucleus alone gets five of the 33 pages on M31 and its satellite galaxies.

Images, diagrams and tables abound. Every constellation has a finder chart for its featured objects. Tales of important astronomers appear in relevant spots. Volume 2 ends with a 70-page glossary not just defining terms, but putting each into wider context, an education in itself.

Dip around here and there, and the authors' secret agenda becomes evident. They inveigle you in with, say, an orbit diagram of the close visual binary Zeta Aquarii (currently a nice test for a 7.5-cm scope), and from there they draw you into Zeta Aquarii's last 60 years of revelations, controversies and ever-improving analyses — educating you in astrophysics and instrumental methods along the way. It's an education on the sly.

These books are object- and personality-based, not theory- and principle-based. But they'll be my bedtime reading for years to come.

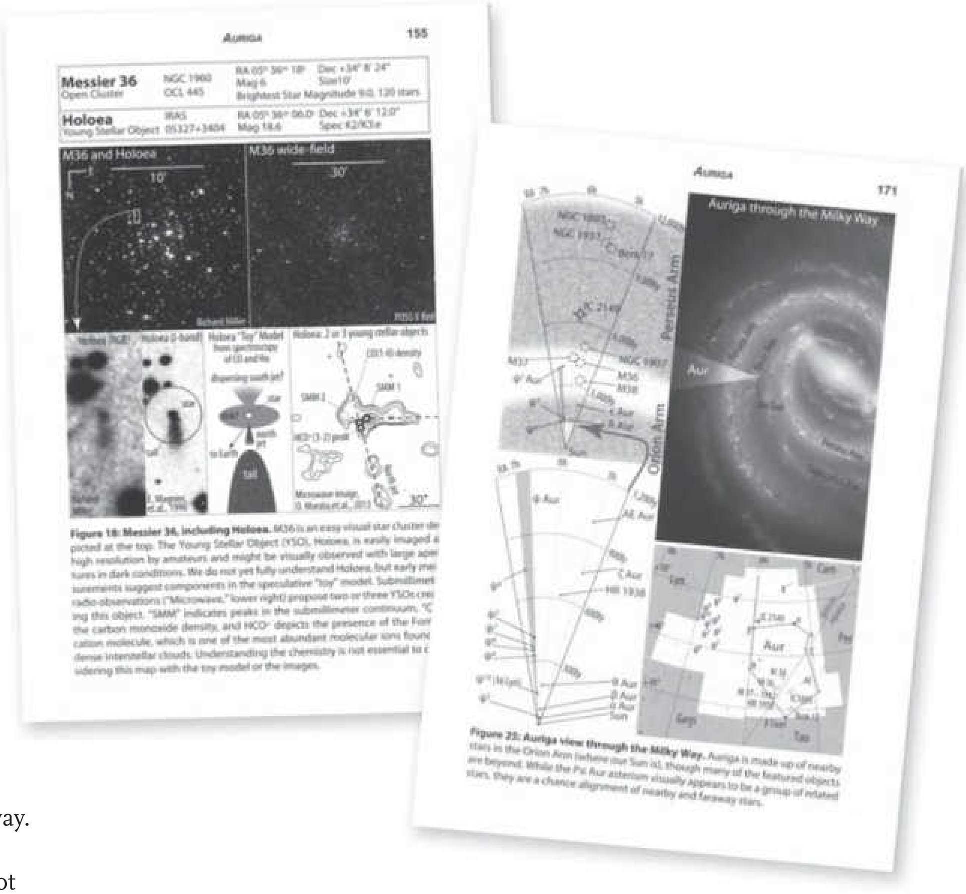
Criticisms? A treatment of this depth ought to have more about how the objects appear visually through scopes of different apertures, I would think. And sometimes the text could have used another editor's run-through for smoothness and elegance.

Perry Remaklus, the man behind Willmann Bell, says that Kanipe is currently working on Volume 5. "We spent seven years planning this thing out before we even launched the first two volumes," Remaklus says. At this rate *Annals of the Deep Sky* will span more than a dozen 350-page volumes by the time it reaches Vulpecula at the alphabet's end.

By then the science in the first ones will surely be getting dated. But Remaklus sees this series as a permanent living thing, with future editors reworking the volumes from beginning to end every decade or two.

If so, the *next* heir to Admiral Smyth may not be required for the rest of the 21st century. ✦

***Alan MacRobert** once offered Robert Burnham, Jr., a chance to update his* Celestial Handbook *for reissuance by Sky Publishing Corporation — but Burnham, by then a hermit in the Arizona desert, refused. Suffering from worsening mental health, Burnham spent his last years mostly on a park bench in San Diego selling paintings of cats. He died in 1993 destitute and unnoticed. A biography is at:* ***is.gd/burnhambio**.*



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astronomywa.net.au

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nacaa.org.au

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hbastrosoc.org.nz/rasnz-conference-2016/

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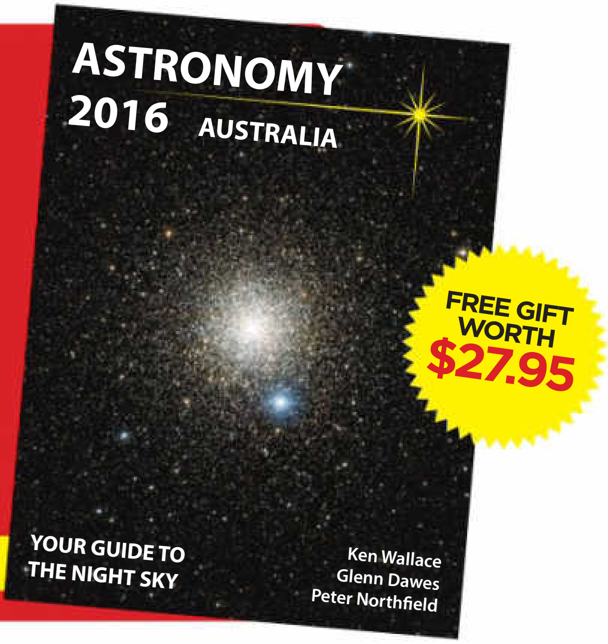

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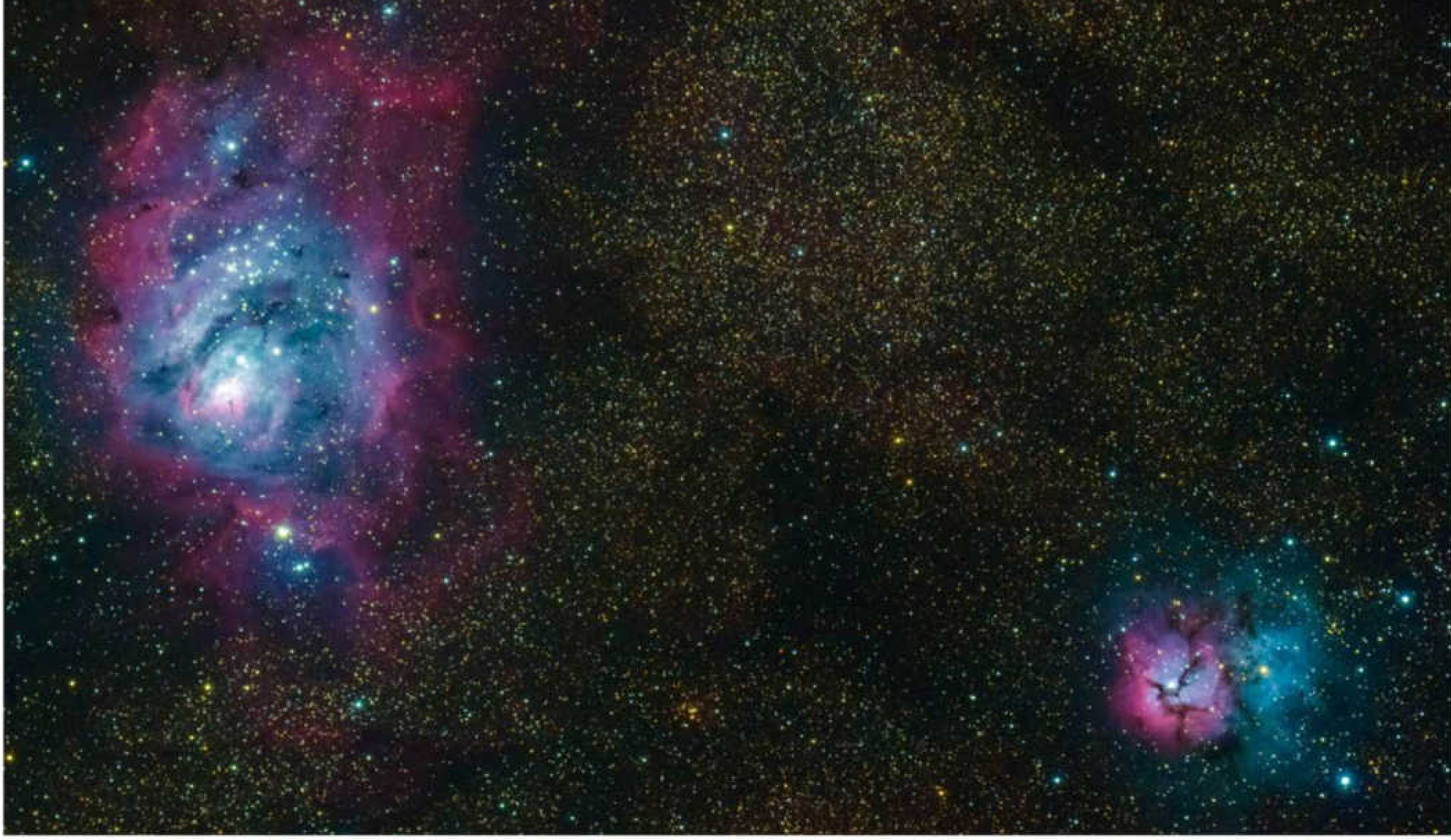
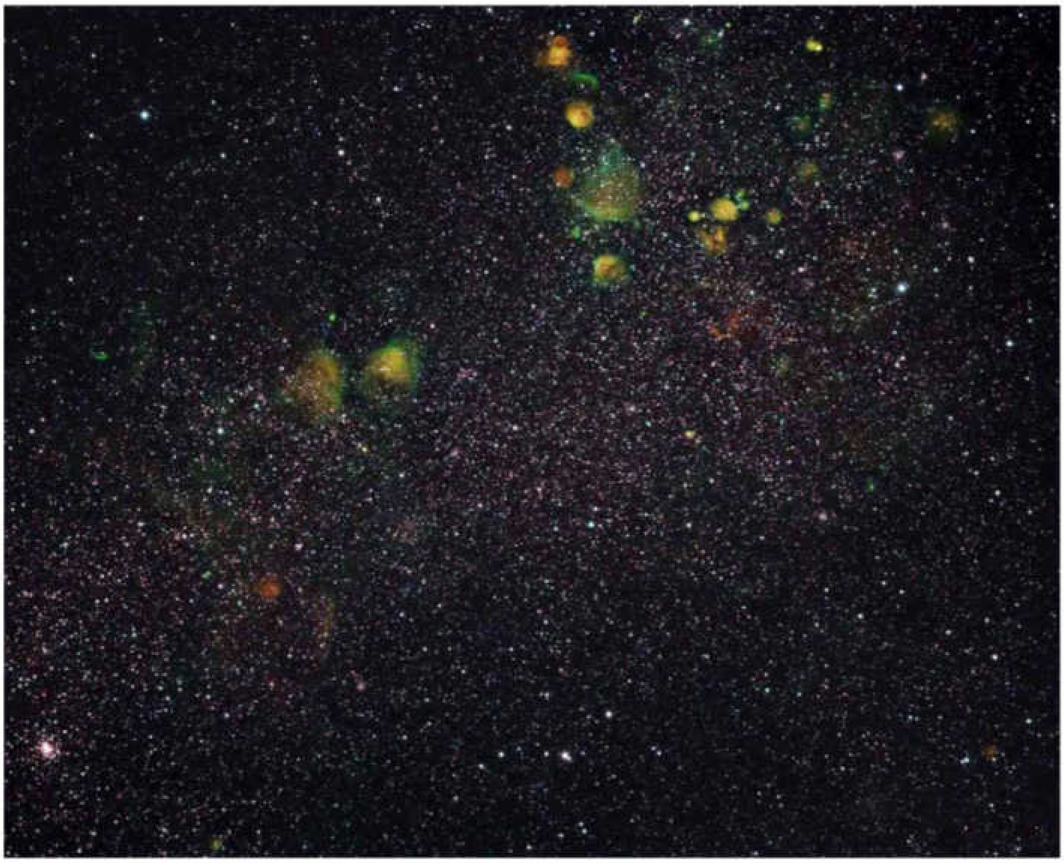
Astrophotos from our readers

▲ **FISH'S NIGHT**
Patrick Day
This shot was taken at a vehicle crash memorial (for a local, Terry 'Fish' Gill) site near Alice Springs. Patrick used a Tokina ATX 116 PRO DXII 11-16mm lens set at 11 mm, and 20 seconds exposure (including illuminating the foreground with a torch).





▲ LAGOON & TRIFID

Cape Tiene

This image of the two famous nebulae was shot over two nights, using a Canon 600d and UV-IR filter on a Skywatcher ED80 and NEQ6. It's a total of 53, 90-second frames at 800iso, stacked and processed with Nebulosity and further processing with Lightroom and Photoshop.

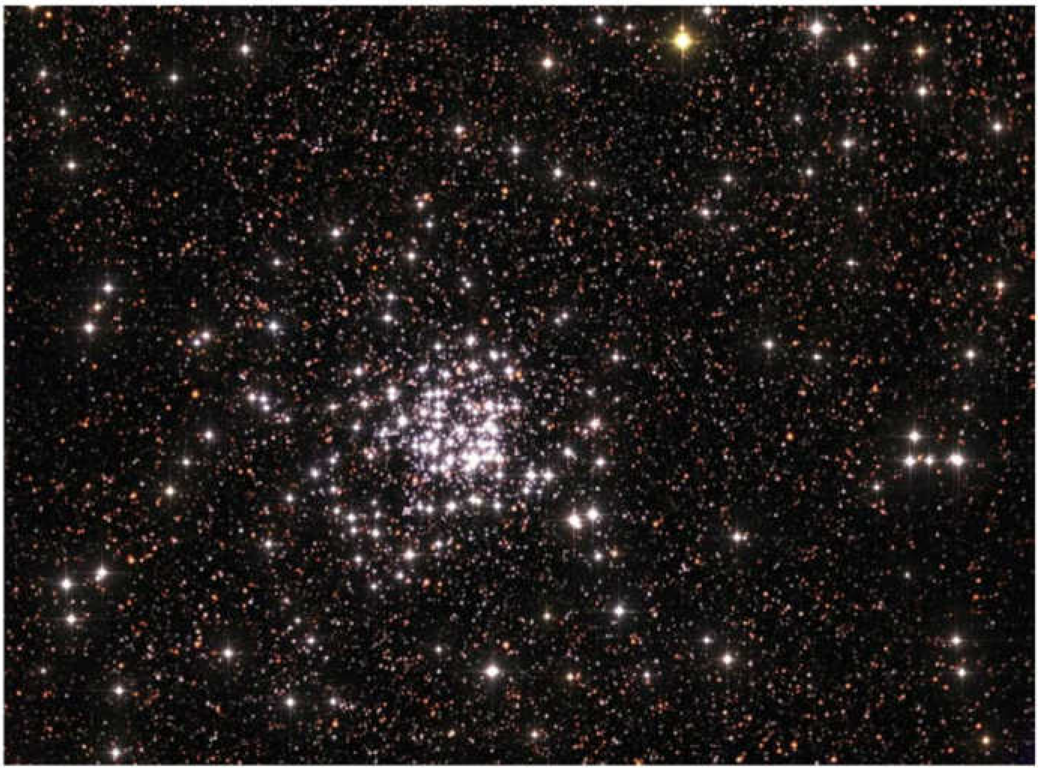
◀ STELLAR BUBBLES

Greg Crawford

The Small Magellanic Cloud looks different when seen through filters that pick out the wavelengths of Ha, OIII and SII. Greg used a William Optics FLT 132 refractor, EQ6 Pro mount, Atik Titan guide camera and QSI 683 main camera.

HOW TO SUBMIT YOUR IMAGES

Images should be sent electronically and in high-resolution (up to 10MB per email) to contributions@skyandtelescope.com.au. Please provide full details for each image, eg. date and time taken; telescope and/or lens; mount; imaging equipment type and model; filter (if used); exposure or integration time; and any software processing employed. If your image is published in this Gallery, you'll receive a 3-issue subscription or renewal to the magazine.



◀ WILD DUCK CLUSTER

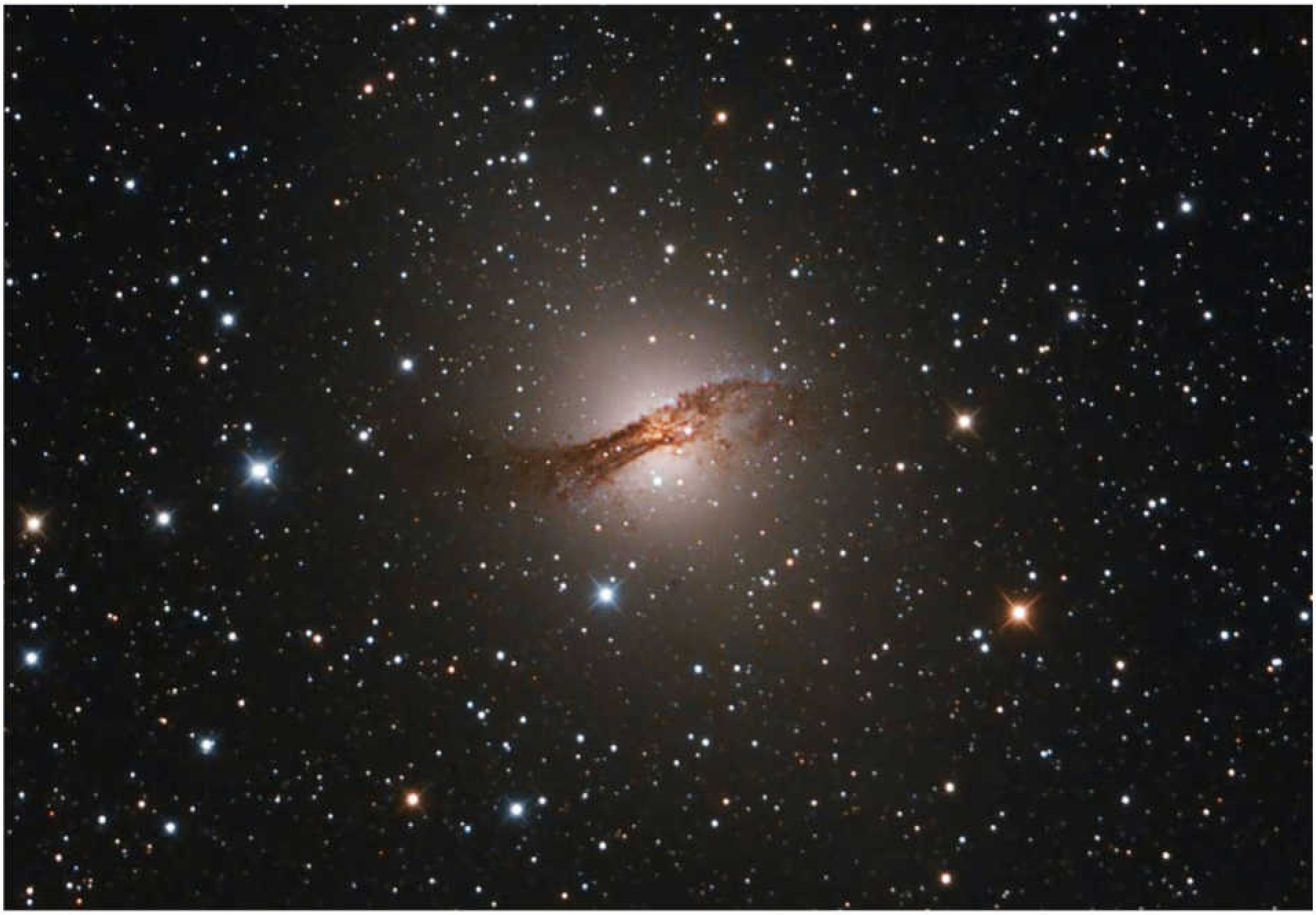
John Dolby

Messier 11 is a group of about 3,000 stars in the constellation Scutum. John used a Celestron 11-inch scope, QSI 583 camera and Astrodon LRGB filters for this shot.

▼ MIGHTY CENTAUR

Paul Montague

Southern galaxy NGC 5128 (also known as Centaurus A, although that name properly refers to the radio source within it) can be spotted with binoculars, though a telescope is needed for detail. Paul used a GSO 20-cm Ritchey-Chretien telescope, a QHY8 camera for a total exposure time of 260 minutes.



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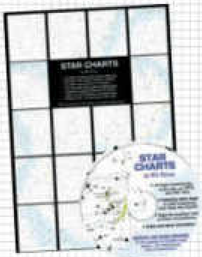

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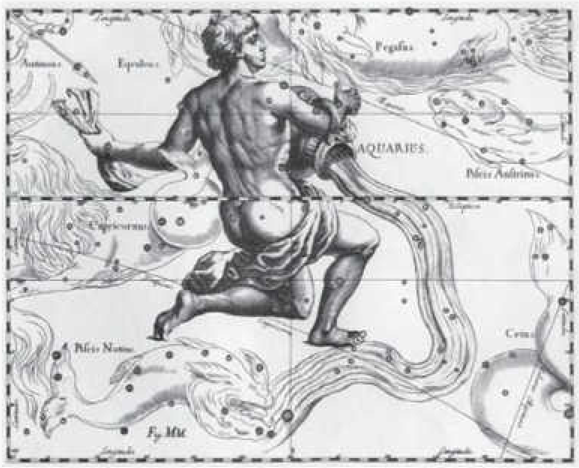
PreciseParts 80
Sheldon & Hammond (Celestron) ... 13, 79, 84
Sirius Optics 58-59
Sky-Watcher 81, 83
VernonScope 50

Aquarius in a loincloth

What worked for Hevelius decidedly did not for one Soviet postal official.

COURTESY ALEX GURSHTEIN



JOHANNES HEVELIUS

Hevelius' Aquarius (right) and Komlev's dressing-up (above). See more images, including the 2004 stamp, at http://is.gd/sovietstamps

> **"He declared that it was utterly unacceptable to expose the delicate morality of the Soviet citizenry to a nude male figure, even a half-turned one."**

With the 30th anniversary this March of the Soviet Vega missions — a pair of spacecraft that investigated Venus before flying past Halley's Comet in March 1986 — I'm reminded again of an amusing event in the former USSR in which I played an indirect role. The event speaks volumes about a bygone era when the Soviet Union was both a planet-exploring powerhouse yet also distinctly less progressive on the public morals front.

It concerns the depiction of Aquarius on a Soviet stamp — one that shows the zodiacal water-bearer quite untraditionally swathed in a kind of loincloth.

For almost 60 years I worked where I was born, in Moscow. In the last decade of my Muscovite life, fate chose to place me on the Artistic Advisory Board of the Ministry of Communications of the USSR. Arising during Gorbachev's *perestroika*, the AAB offered non-binding advice concerning the artistic merits of postage stamps, envelopes and the like being prepared for publication. Its members were primarily artists; as an astronomer and a philatelist, I was the black sheep of this council. In any case, from time to time during AAB meetings, I bore witness to many curious incidents with Soviet stamps.

Such as when, in the early 1980s, artist Gherman Alexeyvich Komlev received an order for three stamps dedicated to the Vega project. The stamps came out at different times and were printed in standard sheets as well as in miniature sheets of eight. To design the margins for one of these miniature sheets, Komlev drew inspiration from Johannes Hevelius' 1690 star atlas — which, as many amateur astronomers know, depicts Aquarius with bare buttocks.

And so it came to pass that the exposed behind of Aquarius, as Komlev sketched it, landed on the desk of the head of the Directorate for the Production and Distribution of Instruments of Postal Revenue. This was the body that gave final approval to all Soviet stamp projects.

Now, the chief of the Directorate at the time was ignorant of mythology and astronomy — or perhaps he simply knew the preferences of upper-level authorities. But without hesitation, he declared that it was utterly unacceptable to expose the delicate morality of the Soviet citizenry to a nude male figure, even a half-turned one, and promptly demanded that the artist alter the design.

To avoid changing the entire, largely approved composition, the hapless Komlev quickly slapped a loincloth onto Aquarius. And in precisely this way the ancient water-bearer saw the light of day in December 1984, on a Soviet minisheet of eight Vega stamps.

Twenty years later, in 2004, the postal service of the new Russia finally realised a proposal I'd first made in my AAB days of publishing 12 stamps with the signs of the zodiac. Among sources for artist Vladimir Beltyukov was once again Hevelius' star atlas. But this time no one in Russia commanded covering up Aquarius' backside. How times change! ✦

Alexander Gurshtein is an astronomer and historian of science at Colorado Mesa University. A former president of the IAU Commission on History of Astronomy, he helped initiate the International Year of Astronomy (2009).